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ABSTRACT

Properties of Foreign Exchange Risk Premiums*

We study the properties of foreign exchange risk premiums that can explain the forward bias puzzle, defined as the tendency of high-interest rate currencies to appreciate rather than depreciate. These risk premiums arise endogenously from the no-arbitrage condition relating the term structure of interest rates and exchange rates. Estimating affine (multi-currency) term structure models reveals a noticeable tradeoff between matching depreciation rates and accuracy in pricing bonds. Risk premiums implied by our global affine model generate unbiased predictions for currency excess returns and are closely related to global risk aversion, the business cycle, and traditional exchange rate fundamentals.

JEL Classification: E43, F31 and G10
Keywords: exchange rates, forward bias, predictability and term structure

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1 Introduction

Uncovered interest rate parity (UIP) postulates that the expected exchange rate change must equal the interest rate differential or (because covered interest parity holds) the forward premium. UIP also forms the economic foundation for the forward unbiasedness hypothesis (FUH), stating that the forward exchange rate should be an unbiased predictor of the future spot rate. The empirical observation that there is a negative association between forward premiums and subsequent exchange rate returns, first noted in Hansen and Hodrick (1980), Bilson (1981), and Fama (1984), implies a rejection of UIP and the FUH. This stylized fact is often termed the 'forward bias puzzle'. A large literature has argued that risk premiums must be at the heart of this observation.

In this paper, we re-examine the relation between the term structure of interest rates and exchange rates by expressing the link between forward and spot exchange rates from the principle of no-arbitrage without assuming risk neutrality. This setting implies that the forward exchange rate is the sum of the expected spot rate plus a time-varying risk premium which compensates both for currency risk and interest rate risk. We start from noting that forward rates are generally biased predictors of future spot exchange rates, and expected spot rate changes comprise a time-varying risk premium in addition to the forward premium. We refer to these general, model-free relations that extend the conventional FUH and UIP - in that they are free of risk preferences and consistent with no-arbitrage - as the 'risk-adjusted FUH' (RA-FUH) and as 'risk-adjusted UIP' (RA-UIP).

To work with the RA-UIP condition empirically, we put structure on the international financial market with a model for interest rate risk and currency risk. We use an affine multi-economy term structure model that relates countries' pricing kernels such that arbitrage-free pricing is ensured. We employ latent factors to model the uncertainty underlying the international economy for two reasons. First, this approach gives us maximum flexibility with respect to the statistical framework even with a relatively small number of factors. Second, we do not have to rely on exogenous observable variables driving the economy which are available only at low frequencies.[1] The design of our multi-economy model

[1]Such economic variables are typically available at quarterly or at best at monthly frequency. In our context this is not feasible, as we are also interested in short horizons such as 1 day or 1 week, and our

follows the pioneering work of Backus et al. (2001) but is more general in that it accounts for interest rate risk arising from fluctuations in the bond market over multiple periods. It also accommodates the findings of Brennan and Xia (2006) and extends their work in that we do not approximate the risk premium but derive the exact functional form of the term structure of foreign exchange risk premiums in closed form. This allows us to jointly match the term structures of interest rates and the term structure of foreign exchange risk premiums in the estimation procedure. Using daily data for six major US dollar exchange rates over the last 20 years, we generate model-implied exchange rate expectations and risk premiums for horizons ranging from 1 day to 4 years.

The global affine model used in this paper is designed to identify the stochastic discount factor that prices both currencies and bonds in all countries examined. However, an empirical tradeoff emerges. Specifically, we estimate two different models: a global model which estimates all foreign term structures of yields and foreign exchange risk premiums conditional on the US pricing kernel, using bond and currency market information; and a set of single-country term structure models that separately estimate countries' pricing kernels from which we then compute implied foreign exchange risk premiums. Depreciation rates implied by the global model closely match observed ones, but at the expense of low accuracy in fitting bond yields. Conversely, single-country term structure models price bonds with high accuracy, but imply depreciation rates very different from actual rates. Since both modeling strategies reveal empirical deficiencies, the choice of the model depends on the objective of the application. To study the properties of foreign exchange risk premiums, we choose the global model.

The empirical results reveal that the RA-UIP model is capable of identifying time-varying risk premiums that closely match observed exchange rate behavior. In particular, they fulfill the two conditions established by Fama (1984) such that the omission of the risk premium in conventional UIP tests results in a forward bias. We then show that the model generates unbiased predictions for exchange rate excess returns. This implies that accounting for risk premiums can be sufficient to resolve the forward bias puzzle without

model estimation is hence based on daily data. However, as discussed below, we relate the model-implied risk premiums to observable economic variables later in the paper to refine our understanding of the drivers of the latent factors.

additionally requiring departures from rational expectations. We also perform a variety of predictive ability tests which, on the one hand, complement evidence that excess returns are predictable, and, on the other hand, further confirm that the RA-UIP model fits the exchange rate data substantially better than UIP and also better than a random walk. Finally, we decompose the risk premium, and show that although there is a compensation for interest rate risk, deviations from UIP and hence excess returns can almost entirely be explained by the premium for currency risk.

We also provide empirical evidence that risk premiums are closely linked to economic variables that proxy for global risk, the US business cycle, and traditional exchange rate fundamentals. The results suggest that expected excess returns reflect flight-to-quality and flight-to-liquidity considerations. Expected excess returns also depend on macroeconomic variables (e.g. output growth, money supply growth, consumption growth) in a way that risk premiums in dollar exchange rates are countercyclical to the US economy. Overall, a large part of expected excess returns can be explained by fundamentals deemed relevant in traditional exchange rate models.

Related literature in more detail Earlier papers that study the link between interest rates and exchange rates with term structure factor models include Nielsen and Saá-Requejo (1993), Saá-Requejo (1994), Bakshi and Chen (1997), and Bansal (1997). A pioneering paper is Backus et al. (2001), who adapt modern (affine) term structure theory to a multi-economy setting. They establish important theoretical relations that must hold in the absence of arbitrage between the pricing kernels and the exchange rate driving the international economy. In their discrete-time one-period setting, they can replicate the puzzle under the following two alternative specifications: either there is a common-idiosyncratic factor structure and interest rates take on negative values with positive probabilities, or global factors and state variables have asymmetric effects on state prices in different countries. Motivated by the latter, related empirical studies, e.g. Dewachter and Maes (2001), Ahn (2004), Inci and Lu (2004), Mosburger and Schneider (2005), and Anderson et al. (2010), elaborate on the effects of local versus global factors in an international economy.[2]

[2]Another recent related article is Leippold and Wu (2007). Instead of using an affine model, they propose a class of multi-currency quadratic models.

Brandt and Santa-Clara (2002) and Anderson et al. (2010) extend affine multi-country term structure models to account for market incompleteness and investigate exchange rate excess volatility.

Brennan and Xia (2006) investigate the relations between the foreign exchange risk premium, exchange rate volatility, and the volatilities of the pricing kernels for the underlying currencies, under the assumption of integrated capital markets. The continuous-time model proposed by Brennan and Xia (2006) jointly determines the term structure of interest rates and an approximation of the risk premium in a no-arbitrage setting. Their analysis suggests that the volatility of exchange rates is associated with the estimated volatility of the relevant pricing kernels, and risk premiums are significantly related to both the estimated volatility of the pricing kernels and the volatility of exchange rates. The estimated risk premiums mostly satisfy the Fama (1984) necessary conditions for explaining the forward bias puzzle, although the puzzle remains in several cases.[3]

The choice of variables and the results from our analysis of the economic drivers of foreign exchange risk premiums is consistent with recent research. Our evidence that expected excess returns are (i) related to global risk aversion is consistent with the flight-to-quality and flight-to-liquidity arguments in Lustig et al. (2010) and Brunnermeier et al. (2008), (ii) countercyclical to the state of the US economy is in line with e.g. Lustig and Verdelhan (2007), De Santis and Fornari (2008), and Lustig et al. (2010), and (iii) driven by traditional exchange rate fundamentals is supported by Engel and West (2005).

The remainder of the paper is set out as follows. Section 2 discusses the link between interest rates and exchange rates in light of previous literature and elaborates the relation between forward and expected spot rates implied by no-arbitrage. We describe the empirical model, the estimation procedure and the criteria applied to evaluate RA-UIP

[3]There are many other papers that try to shed light on the puzzle from other angles than relating the term structure of interest rates of two countries and their exchange rate. Explanations that build on risk premium arguments - based, among others, on equilibrium models or consumption-based asset pricing - include Frankel and Engel (1984), Domowitz and Hakkio (1985), Hodrick (1987), Cumby (1988), Mark (1988), Backus et al. (1993), Bekaert and Hodrick (1993), Bansal et al. (1995), Bekaert (1996), Bekaert et al. (1997), Lustig and Verdelhan (2007), Brunnermeier et al. (2008), Farhi and Gabaix (2011), Jurek (2009), Lustig et al. (2011), Verdelhan (2010), Bansal and Shaliastovich (2010), Farhi et al. (2009), and Menkhoff et al. (2011). Other recent papers look at the puzzle, for instance, in the context of incomplete information processing, e.g. Bacchetta and van Wincoop (2009); differences in developed versus emerging markets, e.g. Bansal and Dahlquist (2000) and Frankel and Poonawala (2010); and the profitability and economic value of currency speculation, e.g. Burnside et al. (2010), and Della Corte et al. (2009).

in Section 3. We present the results in Section 4 and discuss extensions and robustness checks in Section 5. Section 6 presents empirical evidence that financial and macroeconomic variables are important drivers of the foreign exchange risk premium. Section 7 concludes. The Appendix provides technical details on derivations and some estimation procedures. A separate Internet Appendix reports the parameter estimates in detail and provides additional empirical results related to extensions and robustness checks.

2 Exchange rates, interest rates and no-arbitrage

This section defines the fundamental relations linking exchange rates and interest rates, and shows the implications of imposing the no-arbitrage condition in this context. This results in the risk-adjusted variants of UIP and FUH, which are shown to imply intuitive properties for the foreign exchange risk premium.

2.1 Uncovered interest parity and forward unbiasedness

We express exchange rates as domestic currency prices per unity of foreign currency. S_t denotes the spot exchange rate, $F_{t,T}$ is the forward exchange rate for an exchange of currencies at time $T > t$, s_t and $f_{t,T}$ are the corresponding log exchange rates. The domestic and foreign T-period yields of the respective zero bonds are $y_{t,T} \equiv -\log p_{t,T}$ and $y^{\star}_{t,T} \equiv -\log p^{\star}_{t,T}$. Assuming risk-neutrality and rational expectations, UIP postulates that the expected exchange rate change must equal the yield differential or equivalently, because Covered Interest Parity (CIP) holds, the forward premium

$$\mathbb{E}^{\mathbb{P}}_t[\Delta s_{t,T}] = f_{t,T} - s_t = y_{t,T} - y^{\star}_{t,T},$$

where $\Delta s_{t,T} = s_T - s_t$ and $\mathbb{E}^{\mathbb{P}}_t$ denotes the conditional expectation under the physical probability measure. UIP further implies that excess returns, $rx_{t,T} \equiv s_T - f_{t,T}$, should be unpredictable and it also forms the economic foundation for the FUH that the forward rate should be an unbiased predictor of the future spot exchange rate, $f_{t,T} = \mathbb{E}^{\mathbb{P}}_t[s_T]$. Empirical tests are usually performed by estimating the 'Fama regressions' (Fama, 1984)

$$\Delta s_{t,T} = \alpha + \beta(y_{t,T} - y^{\star}_{t,T}) + \eta_{t,T}, \tag{1}$$

$$rx_{t,T} = \alpha + \gamma(y_{t,T} - y^{\star}_{t,T}) + \eta_{t,T}, \tag{2}$$

where $\gamma = \beta - 1$. The null hypotheses that UIP is valid holds if $\alpha = 0$, $\beta = 1$, and $\eta_{t,T}$ is serially uncorrelated. Empirical research has consistently rejected UIP; for surveys see Hodrick (1987), Froot and Thaler (1990), Engel (1996), and Sarno (2005). It is now considered a stylized fact that estimates of β are closer to minus unity than plus unity, implying that higher interest rate currencies tend to appreciate when UIP predicts them to depreciate. This finding is commonly referred to as the 'forward bias puzzle'.

2.2 *Risk-adjusted UIP and FUH under no-arbitrage*

Fama (1984) argues that the forward bias may be caused by a time-varying risk premium $\lambda_{t,T}$ that is priced in forward rates, $f_{t,T} = \mathbb{E}^{\mathbb{P}}_t[s_T] + \lambda_{t,T}$. The omission of $\lambda_{t,T}$ in the Fama regressions results in a value of β below unity if the variance of the risk premium is greater than the variance of the expected depreciation, and the risk premium's covariance with expected exchange rate changes is negative (see e.g. Brennan and Xia, 2006, p. 762);

$$\begin{aligned} &\mathbb{V}^{\mathbb{P}}\left[\lambda_{t,T}\right] > \mathbb{V}^{\mathbb{P}}\left[\mathbb{E}^{\mathbb{P}}_t[\Delta s_{t,T}]\right], \\ &\mathbb{C}ov^{\mathbb{P}}\left[\lambda_{t,T}, \mathbb{E}^{\mathbb{P}}_t[\Delta s_{t,T}]\right] < 0. \end{aligned} \tag{3}$$

We relax the assumption of risk-neutrality and derive risk-adjusted counterparts to the conventional UIP and FUH that endogenize time-varying risk premiums in the spirit of Fama (1984). Since the price of a forward contract changes over time due to both spot rate and interest rate fluctuations, we investigate the relation between spot and forward exchange rates in a no-arbitrage setting with stochastic interest rates. We choose $p_{t,T}$ as the numeraire where the associated probability measure is the T-forward measure $\mathbb{Q}_{\mathbb{T}}$.[4]

[4] See for example Björk (2004, p. 355), or Mele (2009, p. 242).

Combining the no-arbitrage pricing equation with CIP gives

$$F_{t,T} = \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right] = \mathbb{E}_t^{\mathbb{Q}}\left[\frac{d\mathbb{Q}_{\mathbb{T}}}{d\mathbb{Q}} S_T\right]. \tag{4}$$

Hence, under no-arbitrage the forward rate is the expected spot rate under the T-forward measure $\mathbb{Q}_{\mathbb{T}}$ and in general not under the risk neutral measure $\mathbb{Q}$ associated with the bank account $B_t = e^{\int_0^t r_s\,ds}$, where r is the short rate of interest. Only in the case of deterministic interest rates, the Radon-Nikodym derivative $\frac{d\mathbb{Q}_{\mathbb{T}}}{d\mathbb{Q}} = 1$ and hence $\mathbb{Q}$ equals $\mathbb{Q}_{\mathbb{T}}$. We term the unbiasedness of the forward rate as a predictor for the expected spot rate under the T-forward measure the risk-adjusted FUH (RA-FUH).

Under the assumption of rational expectations, taking conditional expectation yields the natural right-hand sides of predictive relations for log exchange rate returns

$$\begin{aligned} \Delta s_{t,T} &= \mathbb{E}_t^{\mathbb{P}}\left[s_T - s_t\right] + \varepsilon_{t,T} \\ &= \mathbb{E}_t^{\mathbb{P}}\left[s_T\right] - \left(\log F_{t,T} - (y_{t,T} - y^{\star}_{t,T})\right) + \varepsilon_{t,T} \\ &= \nu_{t,T} + (y_{t,T} - y^{\star}_{t,T}) + \varepsilon_{t,T} \end{aligned} \tag{5}$$

and excess returns

$$rx_{t,T} = \nu_{t,T} + \varepsilon_{t,T} \tag{6}$$

with $\nu_{t,T} = \mathbb{E}_t^{\mathbb{P}}\left[\log S_T\right] - \log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right]$. Expression (5), which we term risk-adjusted UIP (RA-UIP), shows that in the absence of arbitrage exchange rate returns are governed by the yield differential - as postulated by UIP - but additionally comprise a time-varying component $\nu_{t,T}$. This component $\nu_{t,T}$ drives excess returns and since it is determined by the difference in expectations of the (log) spot exchange rate under the physical and the T-forward measure, it reflects risk adjustments. Hence RA-UIP explicitly identifies the risk premium postulated by Fama (1984) as $\lambda_{t,T} = -\nu_{t,T}$. Forward exchange rates in general deviate from future spot exchange rates unless interest rates are deterministic (i.e.

$\mathbb{Q}_{\mathbb{T}} = \mathbb{Q}$) and agents are risk-neutral (i.e. $\mathbb{P} = \mathbb{Q}$).[5] To see this in more detail, note that

$$\mathbb{E}_t^{\mathbb{P}}[s_T] = \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}[s_T] - \Big(\mathbb{E}_t^{\mathbb{Q}}[s_T] - \mathbb{E}_t^{\mathbb{P}}[s_T]\Big) - \Big(\mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}[s_T] - \mathbb{E}_t^{\mathbb{Q}}[s_T]\Big) \tag{7}$$

which allows us to decompose the risk premium $\lambda_{t,T} = -\nu_{t,T}$ as

$$\begin{aligned} \lambda_{t,T} &= \log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}[S_T] - \mathbb{E}_t^{\mathbb{P}}[s_T] \\ &= \underbrace{\Big(\mathbb{E}_t^{\mathbb{Q}}[s_T] - \mathbb{E}_t^{\mathbb{P}}[s_T]\Big)}_{\text{pure currency risk}} + \underbrace{\Big(\log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}[S_T] - \mathbb{E}_t^{\mathbb{Q}}[s_T]\Big)}_{\text{impact of stochastic rates}}. \end{aligned} \tag{8}$$

The first term is a pure currency risk component which reflects corrections for risk aversion, the second term takes into account the impact of interest rates' stochastic nature on the risk premium.[6]

3 The empirical model, estimation and evaluation of RA-UIP

3.1 Affine multi-country term structure model

The RA-FUH and RA-UIP expressions derived in the previous section are model-free relations that extend the conventional FUH and UIP in that they are free of risk preferences and consistent with no-arbitrage. To make these relations amenable for empirical work, we employ a parametric framework that allows to evaluate expressions (5) and (8) in closed form. We use a continuous-time, arbitrage-free dynamic multi-country affine term structure model with latent factors to model the international financial market.[7] The

[5] Even in this extreme case, the risk premium takes into account some mechanical Jensen's type terms, as then $\nu_{t,T} = \mathbb{E}_t^{\mathbb{P}}[\log S_T] - \log \mathbb{E}_t^{\mathbb{P}}[S_T]$ in Eq. (5). These Jensen terms are considered to be very small in currency markets, though; see e.g. the survey of Engel (1996). For completeness and comparison, we provide analogous derivations without logs in Appendix A.

[6] We provide a formal derivation of Eq. (8) in Appendix *A.2*.

[7] It is well-established practice in the term structure literature to employ 3 factors (Litterman and Scheinkman, 1991). For international markets Leippold and Wu (2007) recommend using up to 7 factors per country pair. To keep the model as small as possible and focus on the economic ideas of this paper, we do not estimate such a large model. Instead we allocate 2 factors per country, starting from the domestic economy, which also serves as the common driver behind the international market. Our model is structured such that each foreign economy can be estimated sequentially, while still maintaining rich patterns of correlation between currencies. This parameterization reflects the co-movement between yields in different countries and captures common factors in a parsimonious way. For further reading on term

design of the model is guided by the pioneering work of Backus et al. (2001) as well as the more recent insights of Brennan and Xia (2006). Domestic risk in our model is compensated for with the flexible *extended affine* formulation. Compensation for foreign risk is directly related to domestic risk, but allows for *completely affine* adjustments that are specific to the foreign economy. Our model is flexible enough to meet the conditions formulated by Backus et al. (2001) for their *completely affine* model (asymmetric effects of state variables on state prices in different countries or negative nominal interest rates with positive probability) as well as the relations emphasized by Brennan and Xia (2006) in their *essentially affine* model (association between volatilities of pricing kernels, exchange rates, and risk premiums).

We describe the details of the model in the next subsection. However, three extensions deserve to be mentioned here. First, in contrast to Backus et al. (2001), we use a multi-period setting to account for fluctuations in the bond market; this allows us to disentangle pure currency risk from interest rate risk as in the decomposition in Eq. (8). Second, while Brennan and Xia (2006) use a linear first order approximation in time around the infinitesimal moments of the risk premium, our model produces exact, horizon-dependent risk premiums. As a result, we can derive the term structure of foreign exchange risk premiums in closed form. Third, we estimate our model sequentially for multiple countries, but still maintaining a unique domestic pricing kernel.

3.1.1 A continuous-time model for an international economy

For the econometric analysis, to put structure on the coefficients and error terms appearing in the predictive equation (5), we endow the international financial market with a model for interest rate risk and currency risk. This section therefore engineers a continuous-time, arbitrage-free dynamic term structure model for the global economy, along with exchange rates. The workhorse for this exercise is the framework of affine diffusion processes. To reflect the co-movement between yields in different countries and to capture common factors in a parsimonious way we choose a latent factor setting.

The first building block of the global economy are two domestic factors $(X_{1t}, X_{2t})_{t>0}$

structure models with latent factors, see Duffee (2002, 2006, 2011) and Bikbov and Chernov (2010, 2011).

with a representation in stochastic differential equation (SDE) form under probability measure $\mathbb{M}$

$$d\begin{pmatrix} X_{1t} \\ X_{2t} \end{pmatrix} = \left[\begin{pmatrix} a_1^{\mathbb{M}} \\ a_2^{\mathbb{M}} \end{pmatrix} + \begin{pmatrix} b_{11}^{\mathbb{M}} & 0 \\ b_{21}^{\mathbb{M}} & b_{22}^{\mathbb{M}} \end{pmatrix}\begin{pmatrix} X_{1t} \\ X_{2t} \end{pmatrix}\right] dt + \begin{pmatrix} \sqrt{X_{1t}} & 0 \\ 0 & \sqrt{1+\beta X_{1t}} \end{pmatrix} d\begin{pmatrix} W_{1t}^{\mathbb{M}} \\ W_{2t}^{\mathbb{M}} \end{pmatrix}. \quad (9)$$

These factors also serve as common driver behind the world economy. For each foreign economy $\star_i, i = 1, \dots, n$ we add two additional factors $(X_{1t}^{\star_i}, X_{2t}^{\star_i})_{t>0}$ with SDE representation

$$\begin{aligned} d\begin{pmatrix} X_{1t}^{\star_i} \\ X_{2t}^{\star_i} \end{pmatrix} &= \left[\begin{pmatrix} a_1^{\star_i \mathbb{M}} \\ a_2^{\star_i \mathbb{M}} \end{pmatrix} + \begin{pmatrix} b_{11}^{\star_i \mathbb{M}} & 0 & b_{13}^{\star_i \mathbb{M}} & 0 \\ b_{21}^{\star_i \mathbb{M}} & b_{22}^{\star_i \mathbb{M}} & b_{23}^{\star_i \mathbb{M}} & b_{24}^{\star_i \mathbb{M}} \end{pmatrix}\begin{pmatrix} X_{1t} \\ X_{2t} \\ X_{1t}^{\star_i} \\ X_{2t}^{\star_i} \end{pmatrix}\right] dt \\ &\quad + \begin{pmatrix} \sqrt{X_{1t}^{\star_i}} & 0 \\ 0 & \sqrt{1+\gamma_1^{\star_i} X_{1t} + \gamma_2^{\star_i} X_{1t}^{\star_i}} \end{pmatrix} d\begin{pmatrix} W_{1t}^{\star_i \mathbb{M}} \\ W_{2t}^{\star_i \mathbb{M}} \end{pmatrix}. \end{aligned} \quad (10)$$

Note that the domestic system (9) is a Markov process on its own. The second system (10) is a Markov process only jointly with (9). We define $X_t^{\star_i} \equiv (X_{1t}, X_{1t}^{\star_i}, X_{2t}, X_{2t}^{\star_i})^\top$ for this joint system. The world economy is denoted by $X_t \equiv (X_{1t}, X_{1t}^{\star_1}, \dots, X_{1t}^{\star_n}, X_{2t}, X_{2t}^{\star_1}, \dots, X_{2t}^{\star_n})^\top$. Similarly the Brownian innovations $W_t^{\star_i \mathbb{M}} \equiv (W_{1t}^{\mathbb{M}}, W_{1t}^{\star_i \mathbb{M}}, W_{2t}^{\mathbb{M}}, W_{2t}^{\star_i \mathbb{M}})^\top$ and $W_t^{\mathbb{M}} \equiv (W_{1t}^{\mathbb{M}}, W_{1t}^{\star_1 \mathbb{M}}, \dots, W_{1t}^{\star_n \mathbb{M}}, W_{2t}^{\mathbb{M}}, W_{2t}^{\star_1 \mathbb{M}}, \dots, W_{2t}^{\star_n \mathbb{M}})^\top$. The system of factors driving the world economy can then concisely be written in SDE form

$$dX_t = (a^{\mathbb{M}} + b^{\mathbb{M}} X_t)dt + \sigma(X_t) dW_t^{\mathbb{M}}, \quad (11)$$

where the matrices $a^{\mathbb{M}}, b^{\mathbb{M}}$ and $\sigma(X_t)$ are given in Appendix *B.1*.

For the domestic short rate r_t we assume the functional form $r_t \equiv \delta_0 + \delta^\top X_t^{\star_i} = \delta_0 + \delta_1 X_{1t} + \delta_2 X_{2t}$. Each foreign short rate is specified as $r_t^{\star_i} \equiv \delta_0^{\star_i} + (\delta^{\star_i})^\top X_t^{\star_i} = \delta_0^{\star_i} + \delta_1^{\star_i} X_{1t} + \delta_2^{\star_i} X_{1t}^{\star_i} + \delta_3^{\star_i} X_{2t} + \delta_4^{\star_i} X_{2t}^{\star_i}$. Through the common factors (9) we introduce rich patterns of correlation between the economies. For example, the instantaneous quadratic covariation between the short rates of foreign economies $\star_i$ and $\star_j$ is

$d\langle r_t^{\star_i}, r_t^{\star_j}\rangle = (\delta_1^{\star_i}\delta_1^{\star_j} X_{1t} + \delta_2^{\star_i}\delta_2^{\star_j}(1+\beta X_{1t}))dt$. The constant coefficients in the diffusion functions above are restricted to unity for identification purposes. Factors X_1 and $X_1^{\star_i}$ are square-root processes that drive conditional variance. Factors X_2 and $X_2^{\star_i}$ are conditionally Gaussian to accommodate negative correlation between the state variables, which the yield data usually require; see e.g. Dai and Singleton (2000). With a setting comprised only of square-root processes, correlation would be constrained to be positive, both instantaneously and for a fixed time horizon greater zero.

To ensure arbitrage-free markets, we start by relating the domestic pricing kernel to the pricing kernel and the exchange rate S^i of the $\star_i$ economy

$$\frac{M_t^{\star_i}}{M_0^{\star_i}} \equiv \frac{S_t^i}{S_0^i}\frac{M_t}{M_0}. \tag{12}$$

Here, M is the global pricing kernel in domestic currency, and $M^{\star_i}$ is the global pricing kernel in foreign currency $\star_i$. This relation has been established by Backus et al. (2001). Graveline (2006) notes that it ensures that the foreign pricing kernel is the minimum-variance (MV) kernel, provided the domestic kernel is the MV kernel. This condition puts restrictions on the dynamic behavior of the pricing kernels and the spot exchange rate. It will only be possible to specify the dynamics of two of the three constituents of (12), while the third will be determined endogenously. Our dynamic specification builds on these ideas. The general guideline is to maintain a tractable model with maximum flexibility. The dynamics of the domestic pricing kernel are

$$\frac{dM_t}{M_t} = -r_t dt - \Lambda(X_t)^\top dW_t^{\mathbb{P}}, \tag{13}$$

where Λ is the solution to

$$\Lambda(x) = \sigma(x)^{-1}\left(a^{\mathbb{P}} + b^{\mathbb{P}}x - (a^{\mathbb{Q}} + b^{\mathbb{Q}}x)\right). \tag{14}$$

The drift matrix $b^{\mathbb{Q}}$ inherits the block form of $b^{\mathbb{P}}$. To unambiguously determine the unconditional mean of the domestic short rate, which is affected by the constant factor loading δ_0 and the unconditional mean of X_2 in a very similar way, we impose $a_2^{\mathbb{Q}} = 0$. The parameters $a_1^{\mathbb{Q}}$ and $a_1^{\star_i\mathbb{Q}}$ are identified through the behavior of the square-root factors X_1 and $X_1^{\star_i}$, in particular near the boundary of the state space. The market price of risk specification Λ follows Cheridito et al. (2007), imposing boundary-nonattainment in addition to the admissibility conditions from Duffie et al. (2003). For stationarity we also require strictly negative eigenvalues of $b^{\mathbb{M}}, \mathbb{M} \in \{\mathbb{P}, \mathbb{Q}, \mathbb{Q}_{\star_1}, \dots, \mathbb{Q}_{\star_n}\}$.

We define the dynamics of the foreign pricing kernel for economy $\star_i$ as

$$\frac{dM_t^{\star_i}}{M_t^{\star_i}} = -r_t^{\star_i} dt - \left(\Lambda(X_t)^\top - \Sigma^{\star_i}\, \sigma(X_t)\right) dW_t^{\mathbb{P}}, \tag{15}$$

where the drift of X_t under $\mathbb{Q}_{\star_i}$ (the foreign $\mathbb{Q}$ measure) solves

$$a^{\mathbb{Q}_{\star_i}} + b^{\mathbb{Q}_{\star_i}}\, x = a^{\mathbb{P}} + b^{\mathbb{P}} x - \sigma(x)(\Lambda(x)^\top - \Sigma^{\star_i}\sigma(x))^\top. \tag{16}$$

Computing the solution to Eqs. (13) and (15) and using Eq. (12) we find that the foreign exchange rate S_t^i evolves according to

$$\frac{dS_t^i}{S_t^i} = (r_t - r_t^{\star_i} + \Sigma^{\star_i}\, \sigma(X_t)\, \Lambda(X_t))dt + \Sigma^{\star_i}\sigma(X_t) dW_t^{\mathbb{P}}, \tag{17}$$

where $\Sigma^{\star_i} \equiv (\Sigma_1^{\star_i}, \Sigma_2^{\star_i}, 0, \dots, 0, \Sigma_{i+2}^{\star_i}, \Sigma_{i+3}^{\star_i}, 0, \dots, 0)$. The corresponding dynamics of s_t^i are then

$$ds_t^i = \left(r_t - r_t^{\star_i} + \Sigma^{\star_i}\, \sigma(X_t)\, \Lambda(X_t) - \frac{1}{2}\Sigma^{\star_i}\, \sigma(X_t)\, \sigma(X_t)^\top\, (\Sigma^{\star_i})^\top\right) dt + \Sigma^{\star_i}\sigma(X_t) dW_t^{\mathbb{P}}, \tag{18}$$

which turn out to be affine in X_t.

The instantaneous covariance matrix of $Z_t^{\star_i} = (X_t^{\star_i}, s_t^i)$ is singular (while $\sigma(x)\sigma(x)^\top$ is non-singular), since we have a 5-dimensional process with only 4 driving Brownian motions. Nevertheless, $Z_t^{\star_i}$ is an affine Markov process under probability measures $\mathbb{P}, \mathbb{Q}$, and $\mathbb{Q}_{\star_i}$. For a fixed time horizon $T > t$ it turns out that the *conditional* covariance matrix of $Z_T^{\star_i} | Z_t^{\star_i}$ is non-singular, in contrast to the instantaneous one. As a consequence of the affine formulation we have that yields and spot predictions based on RA-UIP in Eq. (5)

are all affine in the state variables $Z_t^{\star i}$

$$\bar{y}_{t,T} = -\left(A(T-t) + B(T-t)\, Z_t^{\star i}\right), \tag{19}$$

$$\bar{y}^{\star i}_{t,T} = -\left(A^{\star i}(T-t) + B^{\star i}(T-t)\, Z_t^{\star i}\right), \tag{20}$$

$$\mathbb{E}_t^{\mathbb{P}}\left[s_T^i\right] = AQ^{\star i}(T-t) + BQ^{\star i}(T-t)\, Z_t^{\star i}, \tag{21}$$

$$\begin{aligned} \log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T^i\right] &= \log \frac{\mathbb{E}_t^{\mathbb{Q}}\left[e^{-\int_t^T r_s\, ds}\, e^{S_T^i}\right]}{p_{t,T}} \\ &= \phi^{\star i}(T-t,u) - A^{\star i}(T-t) + \left(\psi^{\star i}(T-t,u) - B^{\star i}(T-t)\right) Z_t \end{aligned} \tag{22}$$

where a bar indicates 'model-implied'. $A(T-t)$, $B(T-t)$ (and $A^{\star i}(T-t), B^{\star i}(T-t)$) in Eqs. (19) and (20) are the solutions $\psi(T-t,0)$ and $\phi(T-t,0)$ from the ordinary differential equation (ODE) in (B.8) with domestic (foreign) $\mathbb{Q}$ parameters respectively; see Appendix *B.2* for details.[8] Eq. (21) can be computed using formula (B.5) with a selection vector F with non-zero entry only for s, and ϕ and ψ in (22) solve the ODE in Eq. (B.8) with initial condition $u = (0,0,0,0,1)$.

3.2 Model estimation

The model described above is formulated in terms of latent state variables. Relative to the small number of these driving state variables, the set of observables that we need to fit is large. One can therefore think of these driving state variables as a low-dimensional representation of observed asset prices, very similar to factor reduction. Our estimation procedure differs from those used in previous research on multi-country affine term structure models in both the methodology as well as in terms of the conceptual setup. First, our methodological framework is Bayesian, which yields a posterior distribution of both latent state variables and the parameters of the model. Employing Markov Chain Monte Carlo (MCMC) methods, the Bayesian methodology allows us to perform parameter inference without resorting to asymptotics, and it provides a very natural way to cope with latent

[8] Writing the yield equations (19) and (20) in terms of the enlarged state vector $Z^{\star i}$ instead of X is just a matter of notational convenience as $\frac{\partial B_{s^i}}{\partial \tau} = 0$ together with the initial condition $B_{s^i}(0) = 0$ imply zero factor loadings on the log exchange rate for any maturity τ.

state variables by treating them as parameters.[9] Second, we consider the *joint* dynamics of the latent state variables with the exchange rate. The evolution of the exchange rate therefore affects the distribution of the parameters. Third, in the estimation procedure we do not only fit bond yields in the US and the foreign country but also match the predictive relation implied by RA-UIP derived in Eq. (5). In other words, we jointly fit the domestic and foreign term structures of interest rates as well as the term structure of foreign exchange risk premiums.

To ensure a unique US pricing kernel we estimate the model in two steps. We first estimate the two-factor model (9) on the US term structure. We then estimate the foreign economies (term structures, as well as foreign exchange data) by adding a two-factor system (10) per additional country. The collection of domestic and foreign systems in Eq. (11) is parameterized for sequential estimation and we estimate the foreign economies *conditional* on the US factors which therefore also serve as common drivers behind the world economy. Details of the estimation procedure can be found in Appendix D.

3.3 Model evaluation

In contrast to the standard formulation of UIP, the RA-UIP introduced in this paper explicitly accounts for a time-varying risk premium that arises from the assumption of no-arbitrage. This section describes how we assess whether the model is capable of identifying the risk premium. The RA-UIP model predictions for exchange rate changes $\Delta\widehat{s}_{t,T}$ and excess returns $\widehat{rx}_{t,T}$ are obtained from Eqs. (5) and (6) using the estimation procedure outlined in the previous section.[10]

As a first step, we check whether the model risk premium, $\widehat{\lambda}_{t,T} = -\widehat{\nu}_{t,T}$, fulfills the conditions formulated by Fama (1984), given in Eq. (3): first, the variance of the risk premium is greater than the variance of the expected depreciation, $\Delta\widehat{s}_{t,T}$; second, the covariance between the model-implied risk premium and expected depreciation is negative.

[9]This is a non-negligible advantage over Maximum Likelihood estimation, where the state variables are either integrated out, some prices are assumed to be observed without error to back out the state variables, or filters are employed which are either expensive to evaluate, or approximations. For GMM estimation similar constraints apply; see for instance the implied-state GMM approach in Pan (2002).

[10]To be precise, the expressions are evaluated at the multivariate median of the parameter posterior distribution along with a smoothed estimate of the trajectory of the latent state variables.

If the model risk premium satisfies these conditions, its omission in the Fama regression causes β to be lower than unity.

The next step is to analyze whether the risk premium allows for unbiased predictions of excess returns and hence spot rate changes (or whether the risk premium just accounts for part of the forward bias). We therefore regress observed excess returns on the RA-UIP model predicted excess returns $\widehat{rx}_{t,T}$

$$rx_{t,T} = \alpha' + \beta' \widehat{rx}_{t,T} + \eta'_{t,T} \tag{23}$$

and test whether $\alpha' = 0$ and whether the slope coefficients are statistically significant and if $\beta' = 1$. If we cannot reject that $\alpha' = 0$ and $\beta' = 1$, this indicates that accounting for the risk premium *can* be sufficient to resolve the forward bias puzzle without additionally requiring departures from rational expectations.

Finally, we assess the predictive accuracy of the model by using four additional evaluation criteria: the hit-ratio (HR), an $R2$-measure, the test proposed by Clark and West (2007) based on mean squared prediction errors (CW), and the Giacomini and White (2006) test for conditional predictive ability (GW). The predictions are all in-sample predictions, because our focus is not to provide forecasting models but to evaluate departures from UIP.[11] In other words, we have a twofold motivation for applying these criteria: first, we gain additional insight on the model's goodness of fit as compared to only considering the R^2 of regression (23). Second, we complement the evidence on the predictability of excess returns by assessing the predictive ability of the model per se as well as relative to the benchmark predictions based on UIP and a random walk (RW) without drift. These results will show whether empirical exchange rate dynamics are more adequately characterized by RA-UIP, UIP or the RW.

We apply the four evaluation criteria to compare the accuracy of the RA-UIP model predictions for excess returns, $\widehat{rx}_{t,T}$, to predictions based on the benchmarks. The UIP predicted exchange rate change is given by $\Delta\widehat{s}^{UIP}_{t,T} = (y_{t,T} - y^{\star}_{t,T})$ and the corresponding

[11] Moreover, some recent research argues that it is not clear whether out-of-sample tests of predictability are powerful enough to discriminate among competing predictive variables or models, showing that in-sample tests can be more reliable under certain conditions; e.g. Campbell and Thompson (2008) and the references therein.

excess return prediction is $\widehat{rx}_{t,T}^{UIP} = 0$. The RW predictions are $\Delta\widehat{s}_{t,T}^{RW} = 0$ and $\widehat{rx}_{t,T}^{RW} = -(y_{t,T} - y_{t,T}^{\star})$. HR is calculated as the proportion of times the sign of the excess return is correctly predicted. The remaining criteria are defined as functions of squared prediction errors of the model, SE^M, and of the respective benchmark B, SE^B (where B is either UIP or RW); the respective means are denoted by MSE^M and MSE^B. The $R2$ measure of the model as compared to the benchmark is given by

$$R2 = 1 - \frac{MSE^M}{MSE^B}. \tag{24}$$

Positive values indicate that the model performs better than the benchmark.

The CW test statistic is defined as

$$CW = MSE^B - MSE^M + N^{-1} \sum_{n=1}^{N} \left(\widehat{rx}_{t,T}^{B} - \widehat{rx}_{t,T}^{M} \right)^2, \tag{25}$$

where N is the number of observations in the sample. The CW test allows to compare the predictive ability of the RA-UIP model as compared to that of the nested alternatives. In contrast to other tests which are only based on the difference in MSEs, e.g. Diebold and Mariano (1995), the last term in Eq. (25) adjusts for the upward bias in MSE^M caused by parameter estimates in the larger model whose population values are zero and just introduce noise. In the empirical analysis, we apply the block bootstrap procedure described in Appendix F to obtain p-values for the CW test statistics.

To assess the conditional predictive ability of the RA-UIP model, we implement the GW test for the full sample as follows.[12] The predictions are based on the full time-t information set $\mathcal{F}_t$. Using an $\mathcal{F}_t$-measurable test function h_t, we test the null hypothesis that predictions based on the model and the benchmark predictions have equal conditional predictive ability, $H_{0,h} : \mathbb{E}[h_t \Delta L_T] = 0$. ΔL_T denotes the differential in loss functions of the two competing predictions at t for time T; for the case of the squared prediction error loss function, $\Delta L_T = SE_T^B - SE_T^M$. The test function we use is $h_t = (1, \Delta L_t)^\top$. The GW

[12] Although the main focus of Giacomini and White (2006) is on rolling window methods, their results also hold for a fixed estimation sample (p. 1548).

statistic is given by

$$GW = N \left(N^{-1} \sum_{n=1}^{N} h_t \Delta L_T \right)^{\top} \widehat{\Omega}_N^{-1} \left(N^{-1} \sum_{n=1}^{N} h_t \Delta L_T \right) \tag{26}$$

where $\widehat{\Omega}_N^{-1}$ is a consistent estimate of the variance of $h_t \Delta L_T$.[13] The empirical results are based on block-bootstrapped p-values for the GW test statistic.

4 Empirical analysis

4.1 Data

Daily interest rate and spot exchange rate data are obtained from Datastream. Riskless zero-coupon yields are bootstrapped from money market (Libor) rates with maturities of 1, 3, and 6 months and swap rates with maturities of 1, 2, 3 and 4 years. Feldhütter and Lando (2008) show that swap rates are the best parsimonious proxy for riskless rates. The model estimation is performed on daily zero-yields and spot exchange rates for the US dollar against the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), the merged Deutsch mark and euro series (DEM-EUR), the British pound (GBP) and Japanese yen (JPY). The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

To relate the model risk premiums to financial market and macroeconomic variables, we also obtain daily data for the VIX S&P 500 implied volatility index. Data for industrial production and narrow money supply are obtained from the OECD Main Economic Indicators at the monthly frequency for all countries except industrial production in Australia and Switzerland, which is only available quarterly. The sample periods match those mentioned above with the exception of the VIX series which starts in January 1990. To measure US consumption growth, we use consumption data (available quarterly), the consumer price index, and population figures from the International Monetary Fund's *International*

[13] To obtain a HAC consistent estimate for $T - t > 1$ we use the weight function as in Newey and West (1987) with the truncation lag being equal to $T - t - 1$, as suggested by Giacomini and White (2006).

Financial Statistics database.

4.2 Descriptive statistics and Fama regressions

The empirical analysis presented here is based on non-overlapping observations for prediction horizons of 1 day, 1 week, and 1 month. For the longer horizons of 3 months, 1 year, and 4 years we choose a monthly frequency to maintain a reasonable number of data points. Tables 1 and 2 report descriptive statistics for annualized exchange rate returns and yield differentials.

As a preliminary exercise, we estimate the conventional Fama regression (1). The results reported in Table 3 are consistent with the 'forward bias' documented in previous research. While the estimates of the intercept α are in most cases small and statistically insignificantly different from zero, the β estimates are generally negative and different from the UIP theoretical value of unity for all currencies. For the GBP, estimates across all six horizons are positive but only the 4-year β estimate is statistically significant at conventional significance levels.[14] As outlined in Section *2.1*, the two Fama regressions in Eqs. (1) and (2) contain the same information because $\gamma = \beta - 1$. Since $t[\gamma = 0] = t[\beta = 1]$ the results are in line with previous evidence that excess returns are predictable on the basis of the lagged interest differential (forward premium).

4.3 Model estimation results

In this section, we discuss results related to how well our model fits the US and foreign term structures of interest rates as well as observed depreciation rates, and we give economic interpretations to the latent factors that drive the international economy. Further estimation results (parameter estimates, confidence intervals, and properties of market prices of risk) are reported in detail in Internet Appendix AA.

[14]These values are likely to reflect two major UIP reversions the GBP experienced in our sample: the ERM crisis in 1992 and for the 4-year horizon also the impact of the current financial crisis on the UK and its currency.

4.3.1 Yield pricing errors and matching depreciation rates

We present results showing that depreciation rates implied by the global model closely match observed rates and that yield pricing errors are in the range of some recent studies (see e.g. Anderson et al., 2010). The yield pricing errors are, however, substantially larger than those of single-country models, which, conversely, price bonds with high accuracy but imply depreciation rates almost uncorrelated with actual rates.

Panel A of Table 4 summarizes results for the global model. We report the root mean squared pricing errors of the domestic US yields and the respective foreign yields measured in basis points. The other columns report the correlations between model-implied and observed depreciation rates, and results from regressing observed on model-implied depreciation rates; for details related to the corresponding computations see Appendix *B.4*. The correlations range from 0.891 to 0.999. The regression results show that intercepts (c_0) are virtually zero and slope coefficients (c_1) are close to one. Although most c_1 estimates are different from one from a statistical perspective, we find the results very satisfactory from an economic perspective with estimates ranging from 0.94 to 1.22 and R^2s from 0.793 to 0.998.

As mentioned earlier, we also evaluate an alternative specification in which we estimate single-country term structure models and perform an ex-post analysis of the currency implications. In contrast to the global model, this modeling strategy is performed in three steps and does not allow to condition on information from currency markets. We first estimate the domestic pricing kernel using a standard $\mathbb{A}_1(3)$ latent factor model, e.g. Dai and Singleton (2000). In the second step, we use the same specification to estimate the foreign pricing kernel. Third, we compute currency dynamics implied by the pricing kernels using the no-arbitrage relation in Eq. (12). We describe the technical details of this approach in Appendix E. The advantage of this single-country approach estimating domestic and foreign pricing kernels separately is that it effectively allows to use six factors to model two yield curves. In the global model, in which we fix the domestic pricing kernel in the first step and jointly estimate the foreign term structure of interest rates and foreign exchange risk premiums conditional on the domestic pricing kernel in the second step, the two economies are modelled using four factors. The drawbacks of the single-country model are that it does not account for (the empirically observed) covariation of yields across countries and disregards all information available from currency forwards and the dynamics of the exchange rate. The results in Panel B show, as one would expect, on the one hand that the yield pricing errors are lower for the single-country model as compared to those produced by the global model but, on the other hand, also that model-implied depreciation rates do not match observed rates satisfactorily, with correlations between -0.04 and 0.10 and R^2s below 0.0104.

These findings highlight the substantial tradeoff between the accuracy of fitting yield curves and depreciation rates. On the one hand, the single-country model results show that using bond market information alone is not enough to price currencies. On the other hand, forcing affine models to also match exchange rate data results in inferior bond pricing accuracy. Given this tradeoff, the choice of modeling strategy in general depends on the purpose of the empirical application. Since our primary objective is to study the properties of foreign exchange risk premiums (and not to price bonds), we argue that the global model is better suited for the purpose of this paper. In what follows, we report detailed results for the global model and briefly summarize findings from the single-country models in Appendix E.[15]

4.3.2 Interpretation of latent factors

While we examine the drivers of foreign exchange risk premiums later in Section 6, we now perform a factor rotation to gain insights on the forces behind the state variables governing the international economy. Collin-Dufresne et al. (2008) show that the latent factors underlying single-country affine term structure models can be rotated into variables with unambiguous economic interpretations. Building on the results of Litterman and Scheinkman (1991), they further show how to obtain model-independent estimates of the state variables, which allows to estimate their globally identifiable representation and facilitates the interpretation of multi-factor models. We perform three rotations and compare the model-implied processes to their corresponding model-free estimates. The results

[15] Further results for the single-country models are available from the authors upon request.

reported below show that the factor dynamics are strongly related to the information in the US yield curve and to the carry factor (i.e. the interest rate differential) between the US and the foreign country. Technical details and resulting factor loadings are given in Appendix C.

Our model design allows to perform the factor rotation sequentially on a country-by-country basis. For each rotation, we use the factors $X^{\star i}$ defined in Section *3.1.1*. With the first rotation, we investigate how the estimated factor dynamics are related to the US term structure expressed in terms of the level of the instantaneous short rate, the slope, and the quadratic variations of both. We start by rotating the third state variable (the first Gaussian) into the level of the US short rate r_t and subsequently define the slope μ_t as the instantaneous drift of r_t. The remaining two state variables are rotated into the quadratic variations of the short rate and of the slope. As a result, we obtain an observable representation of the model in terms of the instantaneous US short rate level (r_t), slope (μ_t), short rate variance (V_t), and slope variance (U_t),

$$\begin{pmatrix} dV_t \\ dU_t \\ dr_t \\ d\mu_t \end{pmatrix} = \left(\begin{pmatrix} \varphi_V \\ \varphi_U \\ \varphi_r \\ \varphi_\mu \end{pmatrix} + \begin{pmatrix} \vartheta_V & \vartheta_{VU} & 0 & 0 \\ \vartheta_{UV} & \vartheta_U & 0 & 0 \\ 0 & 0 & 0 & 1 \\ \vartheta_{\mu V} & \vartheta_{\mu U} & \vartheta_{\mu r} & \vartheta_\mu \end{pmatrix} \begin{pmatrix} V_t \\ U_t \\ r_t \\ \mu_t \end{pmatrix} \right) dt$$
$$+ \begin{pmatrix} c_1 & c_2 & 0 & 0 \\ d_1 & d_2 & 0 & 0 \\ \delta_{11} & \delta_{12} & \delta_{13} & \delta_{14} \\ \varrho_1 & \varrho_2 & \varrho_3 & \varrho_4 \end{pmatrix} \operatorname{diag} \begin{pmatrix} f_0 + f_1 V_t + f_2 U_t \\ g_0 + g_1 V_t + g_2 U_t \\ y_0 + y_1 V_t + y_2 U_t \\ z_0 + z_1 V_t + z_2 U_t \end{pmatrix} \begin{pmatrix} dW_{1t} \\ dW_{2t} \\ dW_{3t} \\ dW_{4t} \end{pmatrix}.$$

We also follow Collin-Dufresne et al. (2008) in estimating the model-free state variables. We perform a principal components analysis (PCA) to obtain the first three principal components of yield levels and express yield curve derivatives (i.e. level and slope) as sums of derivatives of the PCA loading functions. Using maturities of up to one year, we use lower-order polynomials to extrapolate the loading functions down to zero. We then calculate the model-free estimates of the short rate level (L_t) and slope (Sl_t) based on the fitted polynomials.

Table 5 presents the correlations of the model-implied processes and their model-free counterparts in columns labeled Rotation 1. The level correlations are around 99.6%, the slope correlations are around 50%, and the correlation for the quadratic variations of the two is around 50% and 46% across all countries, with some differences for AUD and CAD because of their shorter sample periods. Overall, the results show that the information in the US yield curve plays a fundamental role in the international economy, as one would expect for a model of USD exchange rates.

In the second rotation, we again rotate the third state variable into the US short rate, r_t, and then rotate the fourth into the differential of the US and the foreign short rate, $r_t - r_t^{\star i}$, to obtain a carry factor. Our motivation to do so is twofold. First, the short rate differential represents the expected instantaneous depreciation under the risk-neutral measure. Second, research on the cross-section of foreign exchange excess returns suggests that the riskiness of different currencies can be understood in terms of a dollar risk factor and a carry risk factor; see e.g. Lustig et al. (2011). V_t and U_t now represent the quadratic variations of the US short rate level and the level differential. We obtain the model-free estimates for the level differential analogously to those of the US level, and Table 5 reports results in columns labeled Rotation 2. For all countries we find - as in Rotation 1 - that we match the US level and a high correlation between its model-implied and observed quadratic variation. For CHF, DEM-EUR, GBP, and JPY we also find high correlations of $r_t - r_t^{\star i}$ with the model-free level differential (40% to 63%) and the related variance processes U_t and $QV_t[L - L^{\star i}]$ (45% to 79%). For these countries, the foreign yield curve contains valuable information not contained in the US curve and thus carry risk is an important factor. For AUD and CAD, the information in the foreign term structure seems less relevant as compared to that in the US curve.

While the second rotation indicates that the short rate differential adds information beyond the US curve, we now check whether the US term structure adds information when the carry factor has been already accounted for. We do so because Lustig et al. (2011) find that the US risk factor essentially captures average excess returns across currencies. In a setting like ours, the carry for each country potentially already incorporates this information because of its bilateral nature. We thus modify the rotation in that we first rotate the third state variable into $r_t - r_t^{\star i}$ and subsequently the fourth into r_t. Table 5 reports results in columns labeled Rotation 3. We find that the level differential has a correlation of more than 96% for all countries and the correlations of the US level range from -5% to 40%. These results suggest that the carry factor already comprises most, but not all of the information contained in the US curve.

Fig. 1 plots the US risk factors and carry risk factors implied by the model and their model-independent counterparts. Overall, the results show that both the US term structure as well as the carry between the US and the foreign country are driving forces behind the latent factor international economy. These results are consistent with recent studies on the cross-section of currency returns; however, in our setting, the carry factor conveys most of the information.

4.4 Model evaluation

To evaluate the RA-UIP model we employ the criteria described in Section *3.3*. The empirical results reveal that the model predictions are unbiased and have higher accuracy than the UIP and RW benchmarks.

4.4.1 Fama conditions and unbiasedness of model predictions

We first verify whether the model risk premium fulfills the conditions in Eq. (3) such that the omission of the risk premium causes a downward bias in the β estimate. To check the first condition whether the variance of the risk premium is greater than that of expected depreciation, we report variance ratios which, if the condition is fulfilled, should be greater than one. The second condition requires a negative correlation between the risk premium and expected depreciation. The variance ratios and correlation coefficients in Table 6 show that both conditions are fulfilled for all currencies except the GBP. Specifically, for the GBP the condition of negative correlation is satisfied across all six horizons but the variance of the risk premium is smaller than than variance of expected depreciation. However, the violation of the variance condition is consistent with the relatively small forward bias reported for the GBP in Table 3. We thus rather view this as a corroboration of the flexibility of the model.

Table 7 presents results for regression (23) by reporting parameter estimates along with block-bootstrapped standard errors in parentheses as well as t-statistics for the null hypothesis of unbiasedness $\beta' = 1$.[16] The table also reports the R^2 of the regressions but we defer a detailed discussion of the model fit to the next subsection where we evaluate the predictive ability criteria described in Section *3.3*. In brief, we find strong evidence that excess return predictions based on the model risk premium are unbiased. All estimates of the intercept α' are very small and not significantly different from zero (except GBP at the 1-day horizon). All estimates of the slope coefficient β' are positive (except GBP and JPY at the 1-day horizon) and are closer to unity and more significant for longer prediction horizons. Parameter estimates are significantly positive across all horizons for AUD, CAD, CHF, and DEM-EUR, for horizons longer than 1 week for the JPY, and at the 4-year horizon for the GBP. At the same time the estimates of β' are not statistically different from unity except at the very short horizons in some cases. The less pronounced evidence for the GBP is again consistent with the comparably smaller forward bias as judged by the Fama regression results in Table 3.

To reiterate, the findings related to the Fama conditions and the unbiasedness of model predictions are consistent with the notion that the time-varying risk premium accounts for the forward bias puzzle. While results from the Fama conditions show that the risk premium has the general properties to cause a downward bias in the β estimate of the Fama regression across horizons, the unbiasedness results strengthen this evidence as they indicate that accounting for the risk premium can be sufficient to resolve the puzzle without requiring departures from rational expectations.

4.4.2 Predictability of excess returns

In Table 8, we present results for the predictive ability criteria discussed in Section *3.3*. The HR, $R2$, CW, and GW measures allow us to gain insight into the model's goodness

[16] We calculate block-bootstrapped standard errors for all subsequent regressions. The block-bootstrap procedure avoids the necessity to rely on asymptotic theory but still allows to handle serial correlation and heteroskedasticity. We also calculate, but do not report, Newey and West (1987) standard errors with the optimal truncation lag chosen as suggested by Andrews (1991). These standard errors are very similar or slightly smaller than those obtained from the block-bootstrap procedure.

of fit as compared to only considering the R^2 of the predictive regression. Furthermore, we complement previous evidence on the predictability of excess returns based on the model per se and as compared to the benchmark predictions based on UIP and the RW.

The HR indicates that the model predictions have high directional accuracy: while the HR is slightly above 50% for the 1-day horizon, it dramatically increases across horizons for all currencies. The highest HR is achieved for the 1-year and 4-year horizons with the largest values across currencies ranging from 68% to 95%.[17] There is evidence that the model fits the data very well in that it replicates the sign of excess returns, i.e. UIP deviations.

The values reported for the $R2$-measure, as defined in Eq. (24), indicate that the model outperforms both benchmarks. The $R2$s are positive for all currencies across all horizons against the UIP benchmark. The $R2$s are also positive across currencies and horizons against the RW benchmark with the exception of negative values at the short horizons for the JPY and for the GBP. A common feature across currencies is that the highest $R2$ is typically reached for the longest horizons, ranging from 31% to 68% against UIP and from 22% to 63% against the RW.[18] In other words, the mean-squared prediction errors of the model are much smaller than those of the benchmarks providing another piece of evidence that the RA-UIP model fits the empirical behavior of exchange rates better than UIP and the RW.

The results for the Clark and West (2007) test and the Giacomini and White (2006) test for conditional predictive ability further support that the model predictions are more accurate than those of the benchmarks. We report p-values for the test statistics which are obtained from the block-bootstrap procedure described in Appendix F. The CW p-values generally decrease with the prediction horizon and indicate that the model predictions significantly outperform UIP predictions for 4 currencies at the 1-day and 1-week horizon, for 5 currencies at the 1 month horizon, and for all 6 currencies at horizons of 3 months or longer. The results for the RW benchmark generally follow the same pattern but

[17] The Pesaran and Timmermann (1992) test statistics for directional accuracy also suggest that most of the HRs are highly significant. Results are omitted to save space but available on request.

[18] The increasing predictability with longer horizons does not result from a mechanical link between short- and long-horizon predictions similar to the arguments of e.g. Cochrane (2001, p. 389) or Boudoukh et al. (2006). Note that we have a different predictor and different dependent variable for each horizon.

exhibit more variability in terms of significance at the shorter horizons. The *GW* results indicate that the model dominates UIP and RW also in terms of conditional predictive ability. Again, the p-values exhibit some cross-currency variability for shorter horizons, but they indicate significantly stronger predictive ability of the model as compared to UIP at horizons beyond 1 month for AUD, CAD, CHF, and DEM-EUR; for the GBP and JPY results are significant at the 1-year and 4-year horizons. The results for the RW benchmark are very similar.

Overall, the predictions from the model dominate those based on the benchmarks, thereby providing evidence that the empirical behavior of exchange rates is more accurately characterized by RA-UIP as compared to UIP or the RW. The superior predictive ability arises from the fact that the model-implied no-arbitrage conditions allow to identify the risk premiums that drive (excess) returns.[19]

4.5 Decomposing foreign exchange risk premiums

Following the derivations of the RA-FUH and RA-UIP in Section *2.2*, we show in Eq. (8) that the foreign exchange risk premium can be decomposed into a pure currency risk component and a second component that accounts for the fact that interest rates are stochastic. Table 9 displays descriptive statistics for estimated risk premiums and their components on an annualized basis.

The premium for pure currency risk can be positive or negative. Consistent with intuition, we find that compensation for bearing interest rate risk is strictly positive. The average interest rate risk premium contributes, depending on the currency, a sizable level to the overall risk premium. However, the standard deviations are very small compared to those of the overall risk premiums.

These results suggest that the variation in foreign exchange risk premiums - and hence deviations from UIP constituting the forward bias puzzle - are largely driven by the pure currency risk component. We redo the empirical model evaluation analysis in Section *4.4* based on model expectations comprising only the pure currency risk component. We find

[19] The finding that no-arbitrage improves predictions has similarly been documented in the term structure literature, see e.g. Ang and Piazzesi (2003), Christensen et al. (2010), Diez de los Rios (2009) and Almeida and Vicente (2008).

that the results (not reported) are qualitatively identical to those above and that quantitative differences are very small. Nevertheless, although the interest rate risk component does not vary much, its sizable contribution to the average level of foreign exchange risk premiums may be relevant in other contexts, for example assessing the profitability of currency speculation, which we do not investigate in this paper.

5 Extensions and robustness checks

We perform various extensions and robustness checks. We first show that for models with a smaller number of latent factors the tradeoff between fitting the term structure of interest rates and fitting depreciation rates is aggravated, mainly at the expense of yield pricing errors. Second, we provide evidence that extending the information set by currency options does not qualitatively change the results, and finally we show that our conclusions are not affected by the recent financial crisis. Detailed empirical results are given in the Internet Appendix.

5.1 Smaller models

In our setting, the international economy is driven by four latent factors. In this Section we investigate a smaller model with only one factor for the domestic economy (which also serves as a common driver behind the world economy) and two factors for the foreign term structure and the exchange rate.[20] We report pricing errors and model-implied depreciation rates as well as predictive regression estimates and predictive ability statistics for these models with three factors in Tables A.2 to A.4.

We find that smaller models also match observed depreciation rates and produce risk premiums that have predictive ability but at the expense of substantially larger yield pricing errors. The RMSEs of US yields range from 11 to 95 basis points (as compared to

[20] Alternatively, we could choose to maintain two factors for the domestic term structure of interest rates (with these factors also being the common drivers behind the world economy) and to only have one factor per foreign country. However, this single factor would have to price both the foreign country's yield curve and generate exchange rate predictions (and dynamics). We therefore argue that the small model specification that we consider in the paper is better suited for the analysis of foreign exchange risk premiums.

the range from 5 to 23 in the larger model) and similarly most of the foreign yield pricing errors are higher. The correlations between model-implied and observed depreciation rates range from 0.954 to 0.999, and regressing observed on model-implied depreciation rates results in slope coefficients between 0.999 and 1.141 and R^2s from 0.852 to 0.999. The properties of model-implied foreign exchange risk premiums, as judged by the regression and predictive ability results reported in Tables A.3 and A.4, are qualitatively similar to those reported for the larger model with some quantitative differences.

Overall, the results illustrate a worsening of the tradeoff between jointly fitting, on the one hand, the domestic and foreign yield curves and, on the other hand, depreciation rates as well as the term structure of foreign exchange risk premiums, mainly at the expense of (domestic) yield pricing errors. As compared to the standard model, the smaller model appears to be overstrained in accomplishing this task.

5.2 Information in currency options

One issue that has arisen in the literature on affine term structure models is that bonds may be insufficient to span fixed income markets and that derivatives may be needed to fully identify pricing kernels.[21] In our model, exchange rate dynamics are driven by the difference in the innovations of two pricing kernels. In the international economy there is no source of risk that exclusively affects exchange rates and hence currency derivatives combine the information embedded in domestic and foreign fixed income derivatives.[22] To analyze whether currency options convey additional information about foreign exchange risk premiums we rely on the concept of model-free implied variance (MFIV).

Britten-Jones and Neuberger (2000) show that MFIV equals the expected realized variance under the risk neutral measure. MFIV is fully determined by current option prices and defined as

$$MFIV_{t,T} = \frac{2}{T-t}\left[\int_0^{F_{t,T}} \frac{P_{t,T}(K)}{p_{t,T}K^2}dK + \int_{F_{t,T}}^{\infty} \frac{C_{t,T}(K)}{p_{t,T}K^2}dK\right]$$

[21] See the work of Collin-Dufresne and Goldstein (2002) on unspanned stochastic volatility and the subsequent literature building on their work; for a recent paper see e.g. Bikbov and Chernov (2009)

[22] That is, since all factors affect exchange rate as well as domestic and foreign interest rate dynamics, currency derivatives can be hedged/replicated using domestic and foreign fixed income derivatives.

where $P_{t,T}(K)$ and $C_{t,T}(K)$ are the respective time-t prices of T-period European put and call options with strike K.[23] To calculate MFIV we use daily currency option data obtained from JP Morgan comprising 1-month implied volatilities for five points, which is standard in currency markets (Carr and Wu, 2007): at-the-money forward (ATMF), 10-delta call, 10-delta put, 25-delta call, and 25-delta put.[24] To calculate implied volatilities and option prices for other strikes, we follow the suggestions of Jiang and Tian (2005).

To incorporate the information conveyed by MFIV, we augment the estimation procedure to require that the model-implied expectation of realized variance matches MFIV for maturities of one month and three months. The MFIV time series are assumed to be observed with cross-sectionally and intertemporally independent observation errors. We assess whether MFIV has additional information content for foreign exchange risk premiums by comparing estimation results with and without currency options. For all currencies, the sample period is January 24, 1996 to October 10, 2008, except for the DEM-EUR series, for which the sample starts on January 1, 1998. We discuss the main estimation results and the properties of foreign exchange risk premiums below. In Internet Appendix BB we report and compare (rotated) parameters for both estimations in detail. Overall, we find that only around 7% of the parameters are statistically different (specifically 17 out of 240 parameters) and that most of these differences occur for the JPY estimations.

The results in Table A.5 reveal that our baseline estimation (Panel A) and the estimation augmented with MFIV (Panel B) produce virtually identical yield pricing errors and model-implied depreciation rates. The largest difference in yield pricing errors across estimations is one basis point for all countries except JPY, where the yield pricing errors are reduced by three and five basis points for maturities of three and four years when conditioning on MFIV. Correlation and regressions results for depreciation rates are very similar. Panel C summarizes descriptives for MFIV estimates and also shows that MFIV

[23] Jiang and Tian (2005) discuss how to inter- and extrapolate when only a finite range of strike prices is available and show that resulting approximation errors are small. They also demonstrate that the MFIV concept is still valid if the underlying asset price process has jumps and they provide evidence that MFIV contains more information than other volatility predictors. For a recent application of the MFIV concept to foreign exchange markets see Della Corte et al. (2011).

[24] Since the data provides implied volatilities and deltas, but not prices directly, we infer strike prices from deltas and implied volatilities and calculate option prices using Garman and Kohlhagen (1983). Note that in FX markets the convention is to multiply put deltas by -100 and call deltas by 100.

pricing errors are satisfactory.

Our empirical analysis suggests that conditioning on the information in currency options does not have a material effect on how well the model matches foreign exchange risk premiums. In general, when we regress realized excess returns on model predictions from both estimations, the slope coefficients in Eq. (2) and the R^2s are very similar; see Tables A.6 and A.7. The predictive accuracy of both models as compared to the UIP and RW benchmarks is very similar as well; see Tables A.8 and A.9. These results suggest that the specification of our model is flexible enough to capture the variance dynamics of exchange rates and hence, for the purpose of this paper, it is not necessary to additionally condition on the information in currency options, perhaps with the exception of the model for the JPY.[25]

5.3 Sample excluding the financial crisis

As mentioned above, we bootstrap zero yields from money market and swap rates based on the argument put forward by Feldhütter and Lando (2008) that these are the best parsimonious proxy for riskless rates. Due to the recent financial crisis this choice may not be innocuous because the rates may be confounded with credit risk. We therefore repeat the empirical analysis for a sample that excludes the financial crisis by only using data until the end of 2006. We present yield errors, predictive regression estimates, and predictive ability statistics in Tables A.13 to A.15. The results are quantitatively very similar and qualitatively identical to those reported for the full sample.

6 Drivers of the risk premium

The above results provide strong empirical support for the existence of time-varying risk premiums as stated by RA-UIP. In this section we show that the time variation in expected excess returns is closely related to global risk measures and to macroeconomic variables.

[25]We also redo the other empirical checks of our analysis (e.g. Fama conditions and drivers of risk premiums) for the shorter sample starting in 1996 for which options data is available. Using the estimations with and without accounting for MFIV we find that the results (not reported) are qualitatively identical and that quantitative differences are very small.

Our proxy for global risk is based on the VIX S&P 500 implied volatility index traded at the CBOE, which is highly correlated with similar volatility indexes in other countries; see e.g. Lustig et al. (2010). Furthermore, the VIX can also be viewed as a proxy for funding liquidity constraints, noted in Brunnermeier et al. (2008). If the VIX captures global risk appetite and funding liquidity constraints, expected currency excess returns should be negatively related to the VIX multiplied by the sign of the yield differential, $sVIX_t \equiv VIX_t \times \text{sign}[y_t - y_t^\star]$: in times of global market uncertainty and higher funding liquidity constraints, investors demand higher risk premiums on high yield currencies while they accept lower (or more negative) risk premiums on low yield currencies, consistent with 'flight-to-quality' and 'flight-to-liquidity' arguments.[26]

Recent research suggests that risk premiums on US exchange rates are countercyclical to the US economy, similar to risk premiums in other markets; see e.g. Lustig and Verdelhan (2007), De Santis and Fornari (2008), and Lustig et al. (2010). As proxies for the state of the US economy, we use industrial production (IP_t) as a measure of output, and M1 as a measure for narrow money supply (NM_t). Using monthly data, the growth rates ΔIP_t and ΔNM_t are defined as 1-year log changes. If the model risk premium is countercyclical, the relation between expected excess returns and output growth should be negative, whereas the relation with money growth should be positive.

Lustig and Verdelhan (2007) show that high interest rate currencies depreciate on average when domestic consumption growth is low while low interest rate currencies appreciate under the same conditions. They argue that low interest rate currencies hence provide domestic investors with a hedge against aggregate domestic consumption growth risk. We construct a quarterly series of US consumption based on total private consumption deflated by the consumer price index and divided by population figures to obtain per capita consumption. Consumption growth is defined as the 1-year log change. To account for the asymmetric effect of low versus high interest rate currencies, we multiply consumption growth by the sign of the yield differential. The findings of Lustig and Verdelhan (2007) suggest that expected excess returns should be negatively related to signed consumption

[26] We also use the TED spread (difference between the 3-month Eurodollar rate and the 3-month Treasury rate) as an alternative proxy. The results are similar to those based on the VIX reported in the paper; this is in line with Brunnermeier et al. (2008).

growth $s\Delta CO_t$.

Finally, we relate the risk premium to macroeconomic variables deemed relevant in traditional monetary models of the exchange rate. As a proxy for exchange rate fundamentals we use the "observable fundamentals" as in Engel and West (2005), defined as the country differential in money supply minus the country differential in output. We measure output and money supply in the foreign countries analogously to the US variables and define the change in observable fundamentals as $\Delta OF_t = (\Delta NM_t - \Delta NM_t^{\star}) - (\Delta IP_t - \Delta IP_t^{\star})$. Traditional exchange rate models suggest that the relation between these fundamentals and expected excess returns should be positive.

Table 10 presents contemporaneous correlations of expected excess returns with the variables described above; the significance indicated by the asterisks is judged by block bootstrapped standard errors which are not reported to save space. The correlations strongly support our priors as all coefficients are signed correctly across currencies and horizons, in most cases with a high level of significance. These results thus suggest that foreign exchange risk premiums are driven by global risk perception and macroeconomic variables in a way that is consistent with economic intuition.

We also run univariate regressions of expected excess returns on the signed VIX, signed consumption growth, and the observable fundamentals, as well as multivariate regressions on combinations of these variables. We report OLS estimates in Table 11. The univariate results confirm the correlation analysis for the three proxies in terms of sign and statistical significance of coefficients, in most cases accompanied with large explanatory power (as judged by the R^2). The signed VIX has lowest explanatory power for the GBP, but for all other currencies it is substantial: at the 1-day horizon the R^2 ranges from 0.03 to 0.38, at the 1-year horizon it ranges from 0.20 to 0.73. The regressions of expected excess returns on observable fundamentals (for horizons of 3 months and 1 year) produces R^2s in the range of 0.20 to 0.30 for CHF and GBP and in the range of 0.48 to 0.72 for the other currencies. The results for signed consumption growth suggest low explanatory power for the GBP but R^2s for all other currencies range from 0.29 to 0.67.

In the multivariate regression analysis we combine the observable fundamentals with either the signed VIX or signed consumption growth. The results are very similar for both specifications. Signs and significance of coefficients are similar to the univariate regressions but the explanatory power can be substantially larger. The 3-month and 1-year R^2s are lowest for the GBP with values between 0.17 and 0.24, the values for the CHF range from 0.41 to 0.45, and for AUD, CAD, DEM-EUR, and JPY the R^2s are between 0.62 and 0.84.

Overall, we find that the model risk premium is related to global risk aversion, counter-cyclical to the US economy, and associated with traditional exchange rate fundamentals. The few cases in which significance is less pronounced or explanatory power is lower may even corroborate our results. For example, the absence of a strong relation between the GBP and the global risk proxy is consistent with the comparably smaller forward bias in the GBP data set. Also, finding that the CHF is the only currency for which the explanatory power of observable fundamentals is lower than that of the proxies for risk seems consistent with Switzerland being viewed as a 'safe haven' and primarily as a destination for flight-to-quality.

7 Conclusion

There is a large literature documenting the empirical failure of uncovered interest rate parity and of the forward unbiasedness hypothesis: the forward premium is a biased predictor for subsequent exchange rate changes, and the forward rate is a biased predictor for the future spot exchange rate. In this paper we show from the principle of no-arbitrage that currency forwards are in general biased predictors for spot exchange rates, because they not only reflect expected spot rates but additionally comprise time-varying risk premiums that compensate for both currency risk and interest rate risk. We develop an expression for the risk premium and employ it in a prediction model resembling the Fama (1984) regression. Expected exchange rate returns are driven by the yield differential but additionally comprise a time-varying risk premium (Fama's omitted variable), which we estimate from a multi-currency term structure model.

For the empirical analysis, we extend affine term structure models applied in a multi-currency context to explicitly account for these properties of forward rates and embedded risk premiums. We take the model to US exchange rate data and find that there is a tension between fitting bond yields and currency depreciation rates. Single-country models that price bonds with high accuracy imply rates of depreciation that are virtually uncorrelated with actual rates. The global model sacrifices yield pricing accuracy but produces depreciation rates that closely match observed rates, and we thus argue that this model is better suited to study the properties of foreign exchange risk premiums. We find that estimated model expectations and risk premiums satisfy the necessary conditions for explaining the forward bias puzzle. Moreover, the model is capable of producing unbiased predictions for excess returns and hence we conclude that accounting for risk premiums can be sufficient to resolve the forward bias puzzle without additionally requiring departures from rational expectations.

Furthermore, we provide empirical evidence that risk premiums are closely linked to economic variables that proxy for global risk, the US business cycle, and traditional exchange rate fundamentals. Our results suggest that expected excess returns reflect flight-to-quality and flight-to-liquidity considerations, and that they also depend on macroeconomic variables (output growth, money supply growth, consumption growth) such that risk premiums in dollar exchange rates are countercyclical to the US economy.

We disentangle the risk premiums into compensation for currency risk and interest rate risk. We find that the time variation in expected excess returns is almost entirely driven by currency risk. The premium for interest rate risk exhibits very little variation but contributes substantially to the level of risk premiums for some currencies. Given its sizable contribution to the overall level of compensation for risk in foreign exchange markets, interest rate risk should be explicitly accounted for in future research, for instance, when assessing the profitability and economic value of currency speculation.

More generally, additional work is needed to empirically identify a currency's pricing kernel such that it jointly prices returns on all assets denominated in this currency with high accuracy. The results in this paper show that global affine models are unable to price bonds as accurately as single-country models and to simultaneously match observed depreciation rates as well as the term structure of foreign exchange risk premiums. As a consequence, the choice of modeling strategy depends on the purpose of the empirical application. It is thus a challenge for future research to overcome this tradeoff.

A Additional derivations for RA-UIP and RA-FUH

A.1 Predictive relations without logarithms

Analogously to Eqs. (5) and (6) we derive the predictive relations for changes of the spot exchange rate and excess returns without taking logarithms. For the sake of easier readability, we use the same notation for $\varepsilon_{t,T}$, $\nu_{t,T}$; and $\lambda_{t,T}$ here for the case of no logarithms as in the main text where we use logarithms.

Define $\Delta S_{t,T} \equiv (S_T - S_t)/S_t$. Under the assumption of rational expectations, taking conditional expectation yields the natural right-hand side of a predictive relation for the exchange rate return

$$\begin{aligned} \Delta S_{t,T} &= \mathbb{E}_t^{\mathbb{P}}\left[S_T\right]/S_t - 1 + \varepsilon_{t,T} \\ &= \left(\mathbb{E}_t^{\mathbb{P}}\left[S_T\right]/\mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right]\right)e^{(y_{t,T}-y^{\star}_{t,T})} - 1 + \varepsilon_{t,T} \\ &= \nu_{t,T} + e^{(y_{t,T}-y^{\star}_{t,T})} - 1 + \varepsilon_{t,T}, \end{aligned} \tag{A.1}$$

with $\nu_{t,T} = \left(\mathbb{E}_t^{\mathbb{P}}\left[S_T\right]/\mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right] - 1\right)e^{(y_{t,T}-y^{\star}_{t,T})}$. Hence, unless $\mathbb{Q}_{\mathbb{T}} = \mathbb{P}$, i.e. under risk-neutrality and deterministic short rates, there is a time-varying risk premium, $\lambda_{t,T} = -\nu_{t,T}$. Analogously, we find that excess returns defined as $RX_{t,T} = (S_T - F_{t,T})/S_t$ comprise the time-varying risk premium

$$\begin{aligned} RX_{t,T} &= \frac{\mathbb{E}_t^{\mathbb{P}}\left[S_T\right] - \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right]}{S_t} + \varepsilon_{t,T}, \\ &= \frac{\mathbb{E}_t^{\mathbb{P}}\left[S_T\right] - \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right]}{\mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}\left[S_T\right]}e^{(y_{t,T}-y^{\star}_{t,T})} + \varepsilon_{t,T}, \\ &= \nu_{t,T} + \varepsilon_{t,T}. \end{aligned} \tag{A.2}$$

A.2 Decomposition of the risk premium

The relation in Eq. (7) is formally established from

$$\begin{aligned}
\mathbb{E}_t^{\mathbb{Q}_\mathbb{T}}[s_T] &= \mathbb{E}_t^{\mathbb{Q}}\left[\frac{d\mathbb{Q}^T}{d\mathbb{Q}} s_T\right] \\
&= \mathbb{E}_t^{\mathbb{Q}}[s_T] + \mathbb{C}ov_t^{\mathbb{Q}}\left[\frac{d\mathbb{Q}^T}{d\mathbb{Q}}, s_T\right] \\
&= \mathbb{E}_t^{\mathbb{P}}\left[\frac{d\mathbb{Q}}{d\mathbb{P}} s_T\right] + \mathbb{C}ov_t^{\mathbb{Q}}\left[\frac{d\mathbb{Q}^T}{d\mathbb{Q}}, s_T\right] \\
&= \mathbb{E}_t^{\mathbb{P}}[s_T] + \mathbb{C}ov_t^{\mathbb{P}}\left[\frac{d\mathbb{Q}}{d\mathbb{P}}, s_T\right] + \mathbb{C}ov_t^{\mathbb{Q}}\left[\frac{d\mathbb{Q}^T}{d\mathbb{Q}}, s_T\right] \\
&= \mathbb{E}_t^{\mathbb{P}}[s_T] + \left(\mathbb{E}_t^{\mathbb{Q}}[s_T] - \mathbb{E}_t^{\mathbb{P}}[s_T]\right) + \left(\mathbb{E}_t^{\mathbb{Q}_\mathbb{T}}[s_T] - \mathbb{E}_t^{\mathbb{Q}}[s_T]\right).
\end{aligned}$$

B Technical details related to the model

B.1 Drift and diffusion coefficients for the global model

The diffusion function as well as the drift coefficients of the global system (11) are given below under probability measure $\mathbb{M}$

$$a^{\mathbb{M}} = \left(a_1, a_1^{\star_1\mathbb{M}}, \ldots, a_1^{\star_n\mathbb{M}}, a_2^{\mathbb{M}}, a_2^{\star_1\mathbb{M}}, \ldots, a_2^{\star_n\mathbb{M}}\right)^\top. \tag{B.1}$$

The matrix $b^{\mathbb{M}}$ is of the block form

$$b^{\mathbb{M}} = \begin{pmatrix} b_V^{\mathbb{M}} & 0_{n+1\times n+1} \\ b_{VG}^{\mathbb{M}} & b_G^{\mathbb{M}} \end{pmatrix}, \tag{B.2}$$

where matrices b_V, b_{VG}, and b_G are of lower triangular form and $\sigma(X_t)$ is a diagonal matrix

$$b_V^{\mathbb{M}} = \begin{pmatrix} b_{11}^{\mathbb{M}} & & & & \\ b_{11}^{\star_1\mathbb{M}} & b_{13}^{\star_1\mathbb{M}} & & & \\ b_{11}^{\star_2\mathbb{M}} & 0 & b_{13}^{\star_2\mathbb{M}} & & \\ \vdots & \vdots & & \ddots & \\ b_{11}^{\star_n\mathbb{M}} & 0 & \ldots & 0 & b_{13}^{\star_n\mathbb{M}} \end{pmatrix}, b_{VG}^{\mathbb{M}} = \begin{pmatrix} b_{21}^{\mathbb{M}} & & & & \\ b_{21}^{\star_1\mathbb{M}} & b_{23}^{\star_1\mathbb{M}} & & & \\ b_{21}^{\star_2\mathbb{M}} & 0 & b_{23}^{\star_2\mathbb{M}} & & \\ \vdots & \vdots & & \ddots & \\ b_{21}^{\star_n\mathbb{M}} & 0 & \ldots & 0 & b_{23}^{\star_n\mathbb{M}} \end{pmatrix},$$

$$b_G^{\mathbb{M}} = \begin{pmatrix} b_{22}^{\mathbb{M}} & & & & \\ b_{22}^{\star_1\mathbb{M}} & b_{24}^{\star_1\mathbb{M}} & & & \\ b_{22}^{\star_2\mathbb{M}} & 0 & b_{24}^{\star_2\mathbb{M}} & & \\ \vdots & \vdots & & \ddots & \\ b_{22}^{\star_n\mathbb{M}} & 0 & \dots & 0 & b_{24}^{\star_n\mathbb{M}} \end{pmatrix}, \sigma(X_t) = \operatorname{diag} \begin{pmatrix} \sqrt{X_{1t}} \\ \sqrt{X_{1t}^{\star_1}} \\ \vdots \\ \sqrt{X_{1t}^{\star_n}} \\ \sqrt{1+\beta X_{1t}} \\ \sqrt{1+\gamma_1^{\star_1} X_{1t} + \gamma_2^{\star_1} X_{1t}^{\star_1}} \\ \vdots \\ \sqrt{1+\gamma_1^{\star_n} X_{1t} + \gamma_2^{\star_n} X_{1t}^{\star_n}} \end{pmatrix}.$$

B.2 Conditional moments of polynomial processes

It is shown in Cuchiero et al. (2008) that affine processes such as the one used in the present paper are a subclass of polynomial processes. Polynomial processes are particularly attractive because their conditional moments are polynomials in the state variables. The coefficients of the polynomial are determined by the parameters of the process and the time horizon. To be more precise, consider a time-homogeneous (affine) Markov process $X \equiv (X_t)_{t\geq 0, X_0=x_0\in\mathcal{D}}$ living on state space $\mathcal{D} \subset \mathbb{R}^N$. Denote the finite dimensional vector space of all polynomials of degree less than or equal to l by $\mathrm{Pol}_{\leq l}(\mathcal{D})$. An affine process X induces the semigroup

$$P_t f(x) \equiv \mathbb{E}\left[f(X_t)|X_0 = x\right] \in \mathrm{Pol}_{\leq l}(\mathcal{D}) \quad \text{for} \quad f \in \mathrm{Pol}_{\leq l}(\mathcal{D}), \tag{B.3}$$

which maps polynomial moments to polynomials. For affine X_t with state space $\mathcal{D} = \mathbb{R}_+^i \times \mathbb{R}^{N-i}$ define

$$\mu(x) \equiv a + b\,x, \quad V(x) \equiv G + H\,x = G + H_1 x_1 + \cdots + H_i x_i, \tag{B.4}$$

where G is a $N \times N$ matrix and H is a $N \times N \times N$ cube. Polynomial moments can be computed using the semigroup's infinitesimal generator

$$\mathcal{A}f(x) = \frac{1}{2}\sum_{j,l=1}^{N} V_{jl}(x)\frac{\partial^2 f(x)}{\partial x_j \partial x_l} + \sum_{j=1}^{N} \mu_j(x)\frac{\partial f(x)}{\partial x_j}.$$

Choose a basis $E \equiv < e_1, \ldots, e_q >$ of $\mathrm{Pol}_{\leq k}(\mathcal{D})$, where $q = \dim \mathrm{Pol}_{\leq k}(\mathcal{D}) = \sum_{j=0}^{k} \binom{N-1+j}{j}$, and a selection vector $F \equiv < f_1, \ldots, f_q >$. Conditional polynomial moments are then computed according to

$$P_t f = F\, e^{t\,A}\, E^{\top}, \tag{B.5}$$

where $A = (a_{ij})_{i,j=1,\ldots,q}$ is defined implicitly through

$$\mathcal{A} e_i = \sum_{j=1}^{q} a_{ij} e_j. \tag{B.6}$$

For discounted exponential moments we have that

$$\mathbb{E}_t \left[e^{-\int_t^T \delta_0 + \delta_X\, X_s\, ds}\, e^{u X_T} \right] = e^{\phi(\tau,u) + \psi(\tau,u) X_t}, \tag{B.7}$$

where $\phi(\tau, u)$ and $\phi(\tau, u)$ solve a system of Riccati equations with $\tau \equiv T - t$

$$\begin{aligned} \frac{d\psi(\tau,u)}{d\tau} &= -\delta_X + b\,\psi(\tau,u) + \frac{1}{2}\psi(\tau,u)^{\top}\, H\, \psi(\tau,u), \quad \psi(0,u) = u \\ \frac{d\phi(\tau,u)}{d\tau} &= -\delta_0 + a\,\psi(\tau,u) + \frac{1}{2}\psi(\tau,u)^{\top}\, G\, \psi(\tau,u), \quad \phi(0,u) = 0. \end{aligned} \tag{B.8}$$

For $u = (0, 0, \ldots, 0)$ we recognize the bond price equation, for which we will suppress the second argument in the coefficients.

B.3 Second moment of forecast errors

Assuming $L \leq T$ we are interested in the model-implied covariance structure of the error terms from Eq. (5)

$$\begin{aligned} \mathbb{C}ov_t\left[\varepsilon_{t,T}, \varepsilon_{t,L}\right] &= \mathbb{C}ov_t\left[s_T, s_L\right] \\ &= \mathbb{E}_t^{\mathbb{P}}\left[s_T\, s_L\right] - \mathbb{E}_t^{\mathbb{P}}\left[s_T\right] \mathbb{E}_t^{\mathbb{P}}\left[s_L\right] \\ &= \underbrace{\mathbb{E}_t^{\mathbb{P}}\left[\mathbb{E}_L^{\mathbb{P}}\left[s_T\right] s_L\right]}_{I.} - \underbrace{\mathbb{E}_t^{\mathbb{P}}\left[s_T\right] \mathbb{E}_t^{\mathbb{P}}\left[s_L\right]}_{II.}. \end{aligned}$$

$II.$ can be computed according to Eq. (21). For $I.$ we get

$$\mathbb{E}_t^{\mathbb{P}}\left[\mathbb{E}_L^{\mathbb{P}}\left[s_T\right]\, s_L\right] = \mathbb{E}_t^{\mathbb{P}}\left[\left(AQ(T-L) + BQ(T-L)Z_L\right) s_L\right]$$
$$= AQ(T-L)\left(AQ(L-t) + BQ(L-t)Z_t\right) + BQ(T-L)\,\mathbb{E}_t^{\mathbb{P}}\left[Z_L s_L\right]$$

The vector of cross-sectional moments $\mathbb{E}_t^{\mathbb{P}}\left[Z_L s_L\right]$ is a quadratic form in the state variables and can be computed using formula (B.5).

B.4 Model-implied depreciation rates

To assess model-implied depreciation rates we discretize the SDE from system (9) and (10) using a first-order Euler approximation. With daily data the approximation error can be considered to be negligible. We put the posterior estimates of the state variables on a daily grid and put $\iota = 1/255$. Using the posterior point estimates of the parameters with the drift and diffusion expressions of the global system developed in Appendix *B.1* we obtain

$$\sigma(X_t)^{-1}\left(\Delta X_{t+\iota} - (a^{\mathbb{P}} + b^{\mathbb{P}} X_t)\iota\right) \approx \Delta W_{t+\iota}^{\mathbb{P}} \tag{B.9}$$

where $\Delta X_{t+\iota} \equiv X_{t+\iota} - X_t$. The innovations $\Delta W_{t+\iota}^{\mathbb{P}} \equiv W_{t+\iota}^{\mathbb{P}} - W_t^{\mathbb{P}}$ correspond to the Brownian increments from eqs. (9) and (10). Denote with $\Delta s_{t+\iota}^i \equiv s_{t+\iota}^i - s_t^i$. Plugging the Brownian increments $\Delta W_{t+\iota}^{\mathbb{P}}$ together with the state variables X into the discretized Eq. (18) we then obtain a time series of implied depreciation rates

$$\Delta s_{t+\iota}^i = \left(r_t - r_t^{\star_i} + \Sigma^{\star_i}\,\sigma(X_t)\,\Lambda(X_t) - \frac{1}{2}\,\Sigma^{\star_i}\,\sigma(X_t)\,\sigma(X_t)^\top\,(\Sigma^{\star_i})^\top\right)\iota + \Sigma^{\star_i}\sigma(X_t)\Delta W_{t+\iota}^{\mathbb{P}}.$$

C Details related to factor rotations

We perform the factor rotations on a country-by-country basis for each foreign economy $\star_i$. Using the factors $X_t^{\star_i}$, we define $Y_t \equiv (X_{1t}, X_{1t}^{\star_i}, X_{2t}, X_{2t}^{\star_i})^\top$ and omit the country identifier for lighter notation. In all rotations, the first step is to rotate Y_{3t} into

$$\pi_t = \kappa_0 + \sum_{j=1}^{4} \kappa_j Y_{jt}$$

where π_t is the US short rate in Rotations 1 and 2, i.e. $\kappa_0 = \delta_0, \kappa = \delta$, and the short rate differential in Rotation 3, i.e. $\kappa_0 = \delta_0 - \delta_0^{\star_i}, \kappa = \delta - \delta^{\star_i}$. The π_t dynamics are

$$d\pi_t = (\omega_0 + \omega_1 Y_{1t} + \omega_2 Y_{2t} + \omega_3 \pi_t + \omega_4 Y_{4t})\, dt + \sum_{j=1}^{4} \kappa_j \sigma_j dW_{jt}$$

where σ_j denotes the jj-th element of $\sigma(Y_t) \equiv \mathrm{diag}(\sqrt{Y_{1t}}, \sqrt{Y_{2t}}, \sqrt{1+\beta Y_{1t}}, \sqrt{1+\gamma_1^{\star i} Y_{1t} + \gamma_2^{\star i} Y_{2t}})$ and

$$\omega_3 = \frac{\kappa_4 b_{43}}{\kappa_3} + b_{33}, \qquad \omega_0 = \sum_{i=1}^{4} \kappa_i a_i - \kappa_0 \omega_3, \qquad \omega_j = \sum_{i=j}^{4} \kappa_i b_{ij} - \kappa_j \omega_3 \text{ for } j = \{1, 2, 4\}.$$

Given these π_t dynamics, we then rotate Y_{4t} into the process Π_t which either represents the instantaneous slope of the US term structure, the level differential, or the US level:

$$\Pi_t = \Omega_0 + \Omega_1 Y_{1t} + \Omega_2 Y_{2t} + \Omega_3 \pi_t + \Omega_4 Y_{4t}, \qquad \text{where in}$$

- R1 (slope): $\Omega = \omega$, based on slope $\mu_t \equiv \omega_0 + \omega_1 Y_{1t} + \omega_2 Y_{2t} + \omega_3 \pi_t + \omega_4 Y_{4t}$.
- R2 ($r_t - r_t^{\star i}$): $\Omega_3 = \omega_3 - \delta_3^{\star i}/\delta_3$ and $\Omega_j = \omega_j - \delta_j^{\star i} + (\delta_3^{\star i}/\delta_3)\delta_j$ for $j = \{0, 1, 2, 4\}$.
- R3 (r_t): $\Omega_3 = \omega_3 + \delta_3^{\star i}/\delta 3$ and $\Omega_j = \omega_j + \delta_j^{\star i} - (\delta_3^{\star i}/\delta_3)\delta_j$ for $j = \{0, 1, 2, 4\}$.

The dynamics of Π_t are

$$d\Pi_t = (\lambda_0 + \lambda_1 Y_{1t} + \lambda_2 Y_{2t} + \lambda_3 \pi_t + \lambda_4 \Pi_t)dt + \sum_{j=1}^{4} \varrho_j \sigma_j dW_{jt}$$

where

$$\begin{aligned}
\lambda_0 &= \Omega_1 a_1 + \Omega_2 a_2 + \Omega_3 \omega_0 + \Omega_4 a_4 - \Omega_0(\Omega_3(\omega_4/\Omega_4) + b_{44}) + (b_{43}/\kappa_3)(\Omega_0 \kappa_4 - \Omega_4 \kappa_0), \\
\lambda_1 &= \Omega_1 b_{11} + \Omega_2 b_{21} + \Omega_3 \omega_1 + \Omega_4 b_{41} - \Omega_1(\Omega_3(\omega_4/\Omega_4) + b_{44}) + (b_{43}/\kappa_3)(\Omega_1 \kappa_4 - \Omega_4 \kappa_1), \\
\lambda_2 &= \Omega_2 b_{22} + \Omega_3 \omega_2 + \Omega_4 b_{42} - \Omega_2(\Omega_3(\omega_4/\Omega_4) + b_{44}) + (b_{43}/\kappa_3)(\Omega_2 \kappa_4 - \Omega_4 \kappa_2), \\
\lambda_3 &= \Omega_3 \omega_3 - \Omega_3(\Omega_3(\omega_4/\Omega_4) + b_{44}) + (b_{43}/\kappa_3)(\Omega_3 \kappa_4 + \Omega_4), \\
\lambda_4 &= \Omega_3(\omega_4/\Omega_4) + b_{44} - (b_{43}/\kappa_3)\kappa_4, \\
\varrho_3 &= \kappa_3 \Omega_3, \\
\varrho_j &= (\Omega_3 \kappa_j + \Omega_j) \qquad \text{for } j = \{1, 2, 4\}.
\end{aligned}$$

Next, we compute the quadratic variation of π_t and Π_t and define

$$V_t \equiv c_0 + c_1 Y_{1t} + c_2 Y_{2t} \qquad U_t \equiv d_0 + d_1 Y_{1t} + d_2 Y_{2t}$$

where

$$c_0 = \kappa_3^2 + \kappa_4^2 \qquad d_0 = \varrho_3^2 + \varrho_4^2$$
$$c_j = \kappa_j^2 + \kappa_3^2\beta_j + \kappa_4^2\gamma_j \qquad d_j = \varrho_j^2 + \varrho_3^2\beta_j + \varrho_4^2\gamma_j \qquad \text{for } j = \{1,2\}.$$

Note that lower bounds for the variances of π_t and Π_t are given by $\kappa_3^2 + \kappa_4^2$ and $\rho_3^2 + \rho_4^2$ respectively. Solving for Y_1 and Y_2 we get

$$\begin{aligned} Y_1 &= \frac{c_2\left(d_0 - U\right) + d_2\left(V - c_0\right)}{c_1 d_2 - c_2 d_1} \equiv f_0 + f_1 V + f_2 U, \\ Y_2 &= \frac{c_1\left(U - d_0\right) + d_1\left(c_0 - V\right)}{c_1 d_2 - c_2 d_1} \equiv g_0 + g_1 V + g_2 U. \end{aligned}$$

From this, we compute the joint dynamics of (V, U), rewrite π and Π dynamics in terms of V and U and finally obtain the dynamics of the observable system

$$\begin{aligned} \begin{pmatrix} dV_t \\ dU_t \\ d\pi_t \\ d\Pi_t \end{pmatrix} &= \left(\begin{pmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \end{pmatrix} + \begin{pmatrix} \vartheta_{11} & \vartheta_{12} & 0 & 0 \\ \vartheta_{21} & \vartheta_{22} & 0 & 0 \\ \vartheta_{31} & \vartheta_{32} & \vartheta_{33} & \vartheta_{34} \\ \vartheta_{41} & \vartheta_{42} & \vartheta_{43} & \vartheta_{44} \end{pmatrix} \begin{pmatrix} V_t \\ U_t \\ \pi_t \\ \Pi_t \end{pmatrix} \right) dt \\ &+ \begin{pmatrix} c_1 & c_2 & 0 & 0 \\ d_1 & d_2 & 0 & 0 \\ \kappa_1 & \kappa_2 & \kappa_3 & \kappa_4 \\ \varrho_1 & \varrho_2 & \varrho_3 & \varrho_4 \end{pmatrix} \operatorname{diag} \begin{pmatrix} f_0 + f_1 V_t + f_2 U_t \\ g_0 + g_1 V_t + g_2 U_t \\ y_0 + y_1 V_t + y_2 U_t \\ z_0 + z_1 V_t + z_2 U_t \end{pmatrix} \begin{pmatrix} dW_{1t} \\ dW_{2t} \\ dW_{3t} \\ dW_{4t} \end{pmatrix} \end{aligned}$$

where

$$
\begin{aligned}
\varphi_1 &= c_1(a_1 + b_{11}f_0) + c_2(a_2 + b_{21}f_0 + b_{22}g_0), \\
\varphi_2 &= d_1(a_1 + b_{11}f_0) + d_2(a_2 + b_{21}f_0 + b_{22}g_0), \\
\varphi_3 &= \omega_0 + \omega_1 f_0 + \omega_2 g_0 - (\omega_4/\Omega_4)(\Omega_0 + f_0\Omega_1 + g_0\Omega_2), \\
\varphi_4 &= \lambda_0 + \lambda_1 f_0 + \lambda_2 g_0, \\
\vartheta_{1j} &= c_1 b_{11} f_j + c_2(b_{21}f_j + b_{22}g_j) && \text{for } j = \{1,2\}, \\
\vartheta_{2j} &= d_1 b_{11} f_j + d_2(b_{21}f_j + b_{22}g_j) && \text{for } j = \{1,2\}, \\
\vartheta_{3j} &= \omega_1 f_j + \omega_2 g_j - (\omega_4/\Omega_4)(f_j\Omega_1 + g_j\Omega_2) && \text{for } j = \{1,2\}, \\
\vartheta_{33} &= \omega_3 - (\omega_4/\Omega_4)\Omega_3, \\
\vartheta_{34} &= \omega_4/\Omega_4, \\
\vartheta_{4j} &= \lambda_1 f_j + \lambda_2 g_j && \text{for } j = \{1,2\}, \\
\vartheta_{4j} &= \lambda_j && \text{for } j = \{3,4\}, \\
y_0 &= 1 + \beta_1 f_0 + \beta_2 g_0, \\
y_j &= \beta_1 f_j + \beta_2 g_j && \text{for } j = \{1,2\}, \\
z_0 &= 1 + \gamma_1 f_0 + \gamma_2 g_0, \\
z_j &= \gamma_1 f_j + \gamma_2 g_j && \text{for } j = \{1,2\}.
\end{aligned}
$$

D Model estimation

In this section we describe the estimation procedure. The global system in Eq. (11) is specified such that each foreign economy may be estimated sequentially using Eq. (10), conditional on the domestic economcy in Eq. (9). We first describe the estimation of the domestic system using US zero yields in Appendix *D.1*. Second, for each foreign economy $\star_i$ we perform an estimation procedure *conditional* on the estimated domestic system (9); see Appendix *D.2*.

We employ Bayesian methodology. Due to the high-dimensional and nonlinear nature of the econometric problem, we sample the parameters and the latent states using Metropolis-Hastings steps with random walk proposal densities. By construction this proposal yields autocorrelated draws. In each step of the estimation procedure, we therefore generate 10,000,000 samples of which we discard the first 5,000,000. From the remaining draws we take every 1,000th draw to obtain (approximately) independent draws from the posterior distribution. We report parameter estimates of the models in the separate Internet Appendix in Section AA.

D.1 Domestic (US) market

The observed data are seven US zero-yields $y = \{y_t\}$, where $y_t = (y_{t,t+1m}, y_{t,t+3m}, y_{t,t+6m}, y_{t,t+1y}, y_{t,t+2y}, y_{t,t+3y}, y_{t,t+4y})^\top D$ and $D \equiv \text{diag}(12, \cdots, 1/4)$. We assume that yields are observed with cross-sectionally and intertemporally i.i.d. errors $\varrho_t \sim \text{MVN}(0, \Sigma_\varrho)$. Let $\bar{y} = \{\bar{y}_t\}$, where $\bar{y}_t = (\bar{y}_{t,t+1m}, \ldots \bar{y}_{t,t+4y})^\top D$, denote the corresponding model-implied quantities from Eq. (19). We assume that the pricing errors enter additively into the pricing equations

$$y_t = \bar{y}_t + \varrho_t, \tag{D.1}$$

and that the covariance matrix of the errors is diagonal with parameter ζ and $\Sigma_\varrho = \text{diag}(\zeta, \cdots, \zeta)$. Let $\theta^{US} = \left\{a_1^{\mathbb{P}}, a_2^{\mathbb{P}}, \ldots, \delta_1, \delta_2, \zeta\right\}$ be the set of 13 parameters governing the dynamics of the domestic process in Eq. (9). We employ a standard uninformative prior

$$\pi(\theta_i^{US}) \propto \begin{cases} \mathbb{1}_{\{\theta_i^{US} \text{ admissible}\}} & \theta_i^{US} \in \mathbb{R} \\ \frac{\mathbb{1}_{\{\theta_i^{US} \text{ admissible}\}}}{\theta_i^{US}} & \theta_i^{US} \in \mathbb{R}_+ \end{cases} \tag{D.2}$$

and sample from the posterior distribution

$$p(X_1, X_2, \theta^{US} \mid y) \propto p(y \mid X_1, X_2, \theta^{US})\, p(X_1, X_2 \mid \theta^{US})\pi(\theta^{US}) \tag{D.3}$$

by in turn drawing from

$$p(X_1, X_2 \mid y, \theta^{US}) \propto p(y \mid X_1, X_2, \theta^{US})\, p(X_1, X_2 \mid \theta^{US})$$

and

$$p(\theta^{US} \mid y, X_1, X_2) \propto p(y \mid X_1, X_2, \theta^{US})\, p(X_1, X_2 \mid \theta^{US})\pi(\theta^{US})$$

using MCMC methods (Hammersley and Clifford, 1970).[27]

The likelihood of the observation errors is a product of normal densities. To approximate the true, unknown transition density $p(X_1, X_2 \mid \theta^{US})$ we employ a quasi-maximum likelihood density. Denote with $\phi(y; \upsilon, \Omega)$ the density of the multivariate normal distribution with mean υ and covariance Ω. With Y an affine process and θ denoting its parameters, we approximate transition densities of affine processes $p(Y_t \mid Y_{t-1}, \theta)$ with a normal distribution, which has been shown previously to perform well in likelihood-based inference[28]

$$\begin{aligned}
p(X_1, X_2 \mid y, \theta^{US}) &= \prod_{n=2}^{N} p(X_{1n}, X_{2n} \mid X_{1(n-1)}, X_{2(n-1)}, \theta^{US}) \\
&\approx \prod_{n=2}^{N} \phi\left(X_{1n}, X_{2n}; \mathbb{E}^{\mathbb{P}}\left[X_{1n}, X_{2n} \mid X_{1(n-1)}, X_{2(n-1)}\right], \mathbb{V}_t^{\mathbb{P}}\left[X_{1n}, X_{2n} \mid X_{1(n-1)}, X_{2(n-1)}\right]\right).
\end{aligned}$$

The likelihood of the yield pricing errors is

$$p(y \mid X_1, X_2, \theta^{US}) = \prod_{n=1}^{N} \phi\left(y_n; \bar{y}_n, \Sigma_\varrho\right).$$

D.2 Foreign markets

Once we have estimated the domestic system in Eq. (9), we sequentially add foreign economies $\star_i$ as given in Eq. (10) and perform the estimation conditional on the domestic term structure and factors. Through the parameterization introduced in Section *3.1* this approach guarantees a unique domestic pricing kernel and arbitrage-free cross rates in the international economy.

The model ought to fit zero-coupon yields of the respective currencies, represent the joint evolution of the latent state variables with the foreign exchange rate, as well as predict changes in the log spot rate. We observe seven foreign zero-yields $y^{\star_i}$, matching the maturities of the US yields, and the log exchange rate s_t^i. We assume that the exchange rate is

[27] A comprehensive reference for MCMC methods in finance is Johannes and Polson (2009).

[28] We approximate $p(Y_t \mid Y_{t-1}, \theta) \approx \phi(Y_t; \mathbb{E}^{\mathbb{P}}[Y_t \mid Y_{t-1}], \mathbb{V}_t^{\mathbb{P}}[Y_t \mid Y_{t-1}])$, where mean $\mathbb{E}^{\mathbb{P}}[Y_t \mid Y_{t-1}]$ and covariance $\mathbb{V}_t^{\mathbb{P}}[Y_t \mid Y_{t-1}]$ are the first two true conditional moments, which are again computed using formula (B.5) in Appendix *B.2*.

observed without error and that yields are observed with cross-sectionally and intertemporally i.i.d. errors $\varrho_t^{\star i} \sim \text{MVN}(0, \Sigma_{\varrho^{\star i}})$. Let $\bar{y}^{\star i} = \{\bar{y}_t^{\star i}\}$, where $\bar{y}_t^{\star i} = (\bar{y}_{t,t+1m}^{\star i}, \ldots \bar{y}_{t,t+4y}^{\star i})^\top D$ denote the corresponding model-implied quantities from Eq. (20). We assume that the pricing errors enter additively into the pricing equations

$$y_t^{\star i} = \bar{y}_t^{\star i} + \varrho_t^{\star i}. \tag{D.4}$$

For parsimony we again assume that the covariance matrices of the errors are diagonal with parameters $\zeta^{\star i}$, where $\Sigma_{\varrho^{\star i}} = \text{diag}(\zeta^{\star i}, \cdots, \zeta^{\star i})$.

To match model-implied depreciation rates to the data, we implement the predictive equation (5) for horizons of 1 day, 1 week, 1 month, 3 months, 1 year, and 4 years. Specifically, we use the affine formulations for $\mathbb{E}_t^{\mathbb{P}}$ and $\log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}$ given in equations (21) and (22), respectively, to compute the model-implied risk premium $\nu_{t,T} = \mathbb{E}_t^{\mathbb{P}}[s_T^i] - \log \mathbb{E}_t^{\mathbb{Q}_{\mathbb{T}}}[S_t^i]$. Adding up the risk premium and the corresponding yield differential, which we compute using the affine formulations in Eqs. (19) and (20) for domestic and foreign yields, we estimate the expected depreciation by matching the conditional mean to the data. We specify the covariance matrix of prediction errors such that it reflects the cross-sectional covariance structure of the model, $\Sigma_{\varepsilon_t^{\star i}} \equiv \mathbb{V}_t^{\mathbb{P}}[\varepsilon_t^{\star i}]$ with $\varepsilon_t^{\star i} \equiv (\varepsilon_{t,t+1d}^{\star i}, \ldots \varepsilon_{t,t+4y}^{\star i})$. Appendix *B.3* derives how it can be computed as a function of state variables and model parameters. We specify the errors to be normally distributed with mean zero and these model-implied covariances.

Estimation is performed using Bayesian methodology where we employ the usual uninformed prior

$$\pi(\theta_i^{\star i}) \propto \begin{cases} \mathbb{1}_{\{\theta_i^{\star i} \text{ admissible}\}} & \theta_i^{\star i} \in \mathbb{R} \\ \frac{\mathbb{1}_{\{\theta_i^{\star i} \text{ admissible}\}}}{\theta_i^{\star i}} & \theta_i^{\star i} \in \mathbb{R}_+. \end{cases} \tag{D.5}$$

The posterior distribution is

$$p(X_1^{\star i}, X_2^{\star i}, \theta^{\star i} \mid y^\star, s^i, X_1, X_2, \theta^{US}) \propto p(y^{\star i}, s_+^i \mid X^{\star i}, s_-^i, \theta^{\star i}, \theta^{US})\, p(X^{\star i}, s^i \mid \theta^{\star i}, \theta^{US}) \pi(\theta^{\star i}) \tag{D.6}$$

where s^i_+ denotes the log exchange rates to be predicted, and s^i_- denotes the log exchange rates on which the prediction is based. We sample from this high-dimensional and complicated distribution by in turn drawing from

$$p(X_1^{\star i}, X_2^{\star i}, \mid y^\star, s^i, \theta^{\star i}, X_1, X_2, \theta^{US}) \propto p(y^\star, s^i_+ \mid X^{\star i}, s^i_-, \theta^{\star i}, \theta^{US})\, p(X^{\star i}, s^i \mid \theta^{\star i}, \theta^{US})$$

and

$$p(\theta^{\star i} \mid y^{\star i}, s^i, X^{\star i}, \theta^{US}) \propto p(y^\star, s^i_+ \mid X^{\star i}, s^i_-, \theta^{\star i}, \theta^{US})\, p(X^{\star i}, s^i \mid \theta^{\star i}, \theta^{US}) \pi(\theta^{\star i})$$

using MCMC methods (Hammersley and Clifford, 1970). Again we approximate the transition density $p(Z^{\star i} = (X^{\star i}, s^i) \mid \theta^{\star i})$ with the quasi maximum likelihood density

$$\begin{aligned} p(Z^{\star i} \mid \theta^{\star i}) &= \prod_{n=2}^{N} p(Z_n^{\star i} \mid Z_{n-1}^{\star i}, \theta^{\star i}) \\ &\approx \prod_{n=2}^{N} \phi\left(Z_n^{\star i}; \mathbb{E}^{\mathbb{P}}\left[Z_n^{\star i} \mid Z_{n-1}^{\star i}\right], \mathbb{V}_t^{\mathbb{P}}\left[Z_n^{\star i} \mid Z_{n-1}^{\star i}\right]\right). \end{aligned}$$

The density of the yield pricing errors and the exchange rate prediction errors is given by

$$p(y^\star, s^i_+ \mid X^{\star i}, s^i_-, \theta^{\star i}, \theta^{US}) = \prod_{n=1}^{N} \phi\left(y_n^{\star i}; \bar{y}_n^{\star i}, \Sigma_{\varrho^{\star i}}\right) \phi\left(\varepsilon_n^{\star i}; 0, \Sigma_{\varepsilon_n^{\star i}}\right).$$

E Alternative specification: single-country model

As an alternative specification to our global model, we investigate how well estimating single-country term structure models and the currency dynamics implied by the pricing kernels match the data.[29] We describe the model setup and briefly summarize the empirical results below.

[29] In terms of estimation strategy, this approach is similar to the one in Brennan and Xia (2006); the model setup is very different, however. For instance, while Brennan and Xia (2006) model real interest rates using observable state variables, we model nominal interest rates with latent factors, since we are also considering very short horizons for which macro data is not available.

E.1 The single-country model

For each economy, the US and the foreign countries $\star_i$, we estimate a 3-dimensional affine term structure model from the Dai and Singleton (2000) $\mathbb{A}_1(3)$ family. The dynamics for the factors driving the economy, $X_t \equiv (X_{1t}\ X_{2t}\ X_{3t})^\top$, are specified in SDE form as[30]

$$d\begin{pmatrix} X_{1t} \\ X_{2t} \\ X_{3t} \end{pmatrix} = \begin{pmatrix} a_1^{\mathbb{P}} + b_{11}^{\mathbb{P}} X_{1t} \\ a_2^{\mathbb{P}} + b_{21}^{\mathbb{P}} X_{1t} + b_{22}^{\mathbb{P}} X_{2t} \\ a_3^{\mathbb{P}} + b_{31}^{\mathbb{P}} X_{1t} + b_{32}^{\mathbb{P}} X_{2t} + b_{33}^{\mathbb{P}} X_{3t} \end{pmatrix} dt + \operatorname{diag}\begin{pmatrix} \sqrt{X_{1t}} \\ \sqrt{1+\beta X_{1t}} \\ \sqrt{1+\gamma X_{1t}} \end{pmatrix} \begin{pmatrix} dW_{1t}^{\mathbb{P}} \\ dW_{2t}^{\mathbb{P}} \\ dW_{3t}^{\mathbb{P}} \end{pmatrix}. \quad \text{(D.7)}$$

The short rate is assumed to be of the form $r_t \equiv \delta_0 + (\delta)^\top X_t$. To keep the log exchange rate dynamics satisfying the no-arbitrage relation in Eq. (12) affine and tractable, we follow Dai and Singleton (2000) and specify

$$\Lambda(X_t) \equiv \begin{pmatrix} \sqrt{X_{1t}}\lambda_1 \\ \sqrt{1+\beta X_{1t}}\lambda_2 \\ \sqrt{1+\gamma X_{1t}}\lambda_3 \end{pmatrix} \quad \text{(D.8)}$$

and the risk-adjusted drift $\mu^{\mathbb{Q}}$ of dynamics (D.7) is then given by

$$\mu^{\mathbb{Q}}(X_t) = \begin{pmatrix} a_1^{\mathbb{P}} + (b_{11}^{\mathbb{P}} - \lambda_1) X_{1t} \\ a_2^{\mathbb{P}} - \lambda_2 + (b_{21}^{\mathbb{P}} - \beta\lambda_2) X_{1t} + b_{22}^{\mathbb{P}} X_{2t} \\ a_3^{\mathbb{P}} - \lambda_3 + (b_{31}^{\mathbb{P}} - \gamma\lambda_3) X_{1t} + b_{32}^{\mathbb{P}} X_{2t} + b_{33}^{\mathbb{P}} X_{3t} \end{pmatrix}.$$

For each country we estimate the model analogously to the procedure described in Appendix *D.1*. To inspect the implications for exchange rates we compute the dynamics from Eq. (12). We use the US as domestic economy and foreign quantities carry a superscript $\star_i$ as in Section *3.1*

$$\begin{aligned} ds_t^i = &\left(r_t - r_t^{\star_i} + \frac{1}{2}\left(\Lambda(X_t)^\top \Lambda(X_t) - \Lambda^{\star_i}(X_t^{\star_i})^\top \Lambda^{\star_i}(X_t^{\star_i})\right)\right) dt \\ &+ \Lambda(X_t)^\top dW_t^{\mathbb{P}} - \Lambda^{\star_i}(X_t^{\star_i})^\top dW_t^{\star_i \mathbb{P}}. \end{aligned} \quad \text{(D.9)}$$

[30]Note that we use a similar notation for state variables, parameters, etc. as in our global model for the sake of readability.

To obtain model-implied depreciation rates analogous to those for the global model from Appendix *B.4*, we put the posterior estimates of the state variables on a daily grid and put $\iota = 1/255$. From an Euler discretization of Eq. (D.7) we obtain Brownian increments conditional on the states X_t

$$\Delta W^{\mathbb{P}}_{t+\iota} = \operatorname{diag}\begin{pmatrix} \sqrt{X_{1t}} \\ \sqrt{1+\beta X_{1t}} \\ \sqrt{1+\gamma X_{1t}} \end{pmatrix}^{-1} \left(\Delta X_{t+\iota} - \mu^{\mathbb{P}}(X_t)\iota\right), \tag{D.10}$$

with identical discretization for the foreign economies. We then plug these increments into the discretized version of the log-exchange rate dynamics (D.9) to obtain model-implied depreciation rates.

E.2 Summary of empirical results

As discussed in Section *4.3.1*, the single-country model produces smaller yield pricing errors as compared to the global model but the model-implied depreciation rates exhibit only low correlations with observed rates. We also conduct the empirical analysis described in Section *4.4* and summarize the main findings here; detailed results are available from the authors upon request. Consistent with Brennan and Xia (2006) we find that the Fama conditions in (3) are mostly satisfied. Results analogous to Table 6 show that variance ratios across countries range from 0.9937 to 1.0315 and that correlations are very close to -1. The risk premiums implied from the single-country model thus can account for a downward bias in Fama regression estimates. We also find that some slope coefficients in regressions of observed on model-implied excess returns, analogous to Table 7, are significant; however, all slope coefficients are significantly below unity suggesting that these risk premiums are not sufficient to *fully* resolve the forward bias puzzle. Furthermore, several intercepts are non-zero. The predictive ability results, analogous to Table 8, are less pronounced than for the global model; for instance the directional accuracy results reveal that 13 of 36 hit-ratios are less than 50%, whereas for the global model all hit-ratios are greater than 50%. These results support our argument that the global model is better suited for the analysis of foreign exchange risk premiums.

F Block bootstrap procedure

We use the tests proposed by Clark and West (2007) and Giacomini and White (2006) to assess the predictive ability of the model. The null hypothesis of the CW test is that the nested models have equal (adjusted) mean squared errors; under the alternative hypothesis the larger model exploits (additional) predictive information and has a lower mean squared error. The null hypothesis of the GW test is that the models have equal conditional predictive ability; the test statistic is based on the series of squared prediction error differentials. The bootstrap procedure described below computes how often an economy in which there is no predictability would produce as much predictability as found in actual data.

Specifically, we impose a data generating process of no predictability. We consider an overlapping block resampling scheme which can handle serial correlation and also heteroscedasticity; see e.g. Künsch (1989), Hall et al. (1995), Politis and White (2004), Patton et al. (2009). Let y_t be the dependent variable and $\widehat{y}_t$ the prediction of that variable, and proceed as follows:

1. Run the regression of form $y_t = \alpha + \beta\widehat{y}_t + \varepsilon_t$, compute the CW and GW test-statistics, and set $\tilde{y}_t = \hat{\varepsilon}_t$.
2. Form an artificial sample $S_t^* = (y_t^*, \widehat{y}_t^*)$ by randomly sampling, with replacement, b overlapping blocks of length l from the sample $(\tilde{y}, \widehat{y}_t)$.
3. Run the regression $y_t^* = \alpha^* + \beta^*\widehat{y}_t^* + \varepsilon_t^*$, and compute the CW^* and GW^* test-statistics.
4. Repeat steps 2 and 3 5,000 times.
5. Determine the one-sided p-values of the two test-statistics by computing the proportional number of times that $CW^* > CW$ and $GW^* > GW$.

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Table 1: Descriptive Statistics of Exchange Rate Changes

We express exchange rates as domestic currency prices per unity of foreign currency. Log exchange rate returns are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. All figures are annualized. N denotes the number of observations. AC($T-t$) denotes the autocorrelation for the lag being equal to the horizon. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
N	2632	527	120	120	120	120
Mean	0.0042	0.0061	0.0065	0.0025	0.0020	0.0089
Std Dev	0.1048	0.1012	0.0962	0.1009	0.1193	0.1311
Skewness	−0.1745	−0.3243	−0.1458	−0.0555	0.0146	−0.1600
Kurtosis	6.3153	3.6681	2.9266	2.9369	2.5032	1.6528
AC($T-t$)	0.0050	−0.0063	0.1390	0.0776	0.1909	−0.2202
CAD						
N	2989	598	136	136	136	136
Mean	0.0049	0.0055	0.0045	0.0041	0.0077	0.0168
Std Dev	0.0592	0.0601	0.0586	0.0600	0.0607	0.0817
Skewness	0.1058	0.0807	0.2504	0.6931	0.7804	0.3879
Kurtosis	5.2707	3.7735	3.1555	3.9702	3.2926	1.5467
AC($T-t$)	−0.0065	−0.0902	0.0951	0.0312	0.2476	0.3284
CHF						
N	3954	791	180	180	180	180
Mean	0.0234	0.0230	0.0239	0.0222	0.0138	0.0122
Std Dev	0.1134	0.1151	0.1131	0.1174	0.1100	0.0929
Skewness	0.1323	−0.0520	−0.0506	−0.1887	0.0220	−0.3004
Kurtosis	4.8408	3.9049	3.4349	2.8253	2.2132	2.2479
AC($T-t$)	0.0098	−0.0370	0.0899	−0.0864	−0.0380	−0.5532
DEM-EUR						
N	3954	791	180	180	180	180
Mean	0.0167	0.0165	0.0170	0.0151	0.0077	0.0072
Std Dev	0.1043	0.1061	0.1044	0.1109	0.1080	0.1042
Skewness	0.0218	−0.1681	−0.1188	−0.1078	0.1037	−0.1305
Kurtosis	4.6383	3.7138	3.6990	2.6264	2.0779	1.9378
AC($T-t$)	0.0149	−0.0175	0.1361	−0.0764	0.0383	−0.4480
GBP						
N	3954	791	180	180	180	180
Mean	0.0109	0.0105	0.0109	0.0114	0.0071	0.0067
Std Dev	0.0897	0.0960	0.0960	0.0983	0.0876	0.0693
Skewness	−0.1615	−0.8473	−1.0329	−1.1814	−0.3579	−0.0093
Kurtosis	5.6681	8.8557	6.5192	8.1755	3.5891	1.9332
AC($T-t$)	0.0587	0.0211	0.0772	−0.0528	−0.0481	−0.4144
JPY						
N	3954	791	180	180	180	180
Mean	0.0209	0.0208	0.0222	0.0212	0.0207	0.0106
Std Dev	0.1103	0.1178	0.1118	0.1206	0.1054	0.0879
Skewness	0.5513	0.9126	0.4784	0.3244	−0.4827	0.2869
Kurtosis	7.5747	8.6013	4.0976	3.5989	2.5784	3.3482
AC($T-t$)	0.0282	−0.0728	0.0927	−0.0405	0.0882	−0.6362

Table 2: Descriptive Statistics of Yield Differentials

We express exchange rates as domestic currency prices per unity of foreign currency and yield differentials as domestic yields minus foreign yields. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. All figures are annualized. N denotes the number of observations. AC($T-t$) denotes the autocorrelation for the lag being equal to the horizon. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 month	1 year	4 years
AUD						
N	2632	527	120	120	120	120
Mean	−0.0131	−0.0131	−0.0131	−0.0128	−0.0119	−0.0100
Std Dev	0.0010	0.0023	0.0048	0.0084	0.0162	0.0214
Skewness	−0.3051	−0.3061	−0.3349	−0.3190	−0.2261	−0.0673
Kurtosis	1.7540	1.7549	1.7769	1.7445	1.6728	1.4826
AC($T-t$)	0.9994	0.9969	0.9852	0.9630	0.7311	−0.7606
CAD						
N	2989	598	136	136	136	136
Mean	−0.0007	−0.0007	−0.0007	−0.0009	−0.0016	−0.0022
Std Dev	0.0007	0.0017	0.0035	0.0060	0.0110	0.0163
Skewness	0.3745	0.3753	0.3558	0.3259	0.2664	−0.2217
Kurtosis	2.4859	2.4823	2.5052	2.5196	2.5426	2.1107
AC($T-t$)	0.9981	0.9929	0.9639	0.8690	0.4487	−0.5120
CHF						
N	3954	791	180	180	180	180
Mean	0.0112	0.0112	0.0112	0.0113	0.0130	0.0184
Std Dev	0.0016	0.0035	0.0074	0.0125	0.0214	0.0247
Skewness	−0.5354	−0.5367	−0.5466	−0.5492	−0.4674	−0.4514
Kurtosis	2.4617	2.4654	2.493	2.5214	2.5549	3.0721
AC($T-t$)	0.9995	0.9978	0.9900	0.9650	0.7859	−0.4463
DEM-EUR						
N	3954	791	180	180	180	180
Mean	−0.0033	−0.0033	−0.0032	−0.0028	−0.0008	0.0034
Std Dev	0.0016	0.0035	0.0074	0.0125	0.0213	0.0235
Skewness	−0.7088	−0.7087	−0.7178	−0.6905	−0.5951	−0.4391
Kurtosis	2.5272	2.5248	2.5444	2.5393	2.5838	2.9784
AC($T-t$)	0.9998	0.9988	0.9936	0.9730	0.7332	−0.4389
GBP						
N	3954	791	180	180	180	180
Mean	−0.0239	−0.0239	−0.0238	−0.0235	−0.0209	−0.0134
Std Dev	0.0014	0.0031	0.0065	0.0109	0.0181	0.0228
Skewness	−0.7826	−0.7731	−0.7769	−0.7799	−0.7458	−0.5988
Kurtosis	2.4733	2.4506	2.4422	2.4927	2.6521	2.8806
AC($T-t$)	0.9991	0.9964	0.9859	0.9549	0.6958	−0.0064
JPY						
N	3954	791	180	180	180	180
Mean	0.0262	0.0262	0.0263	0.0269	0.0292	0.0333
Std Dev	0.0015	0.0034	0.0071	0.0121	0.0221	0.0319
Skewness	−0.1771	−0.1774	−0.1777	−0.1353	−0.0510	−0.1614
Kurtosis	1.7206	1.7215	1.7298	1.6821	1.6267	1.8823
AC($T-t$)	0.9997	0.9981	0.9918	0.9745	0.7942	−0.1129

Table 3: Fama Regressions

The table shows the results from estimating, by ordinary least squares, the Fama regression (1), $\Delta s_{t,T} = \alpha + \beta(y_{t,T} - y^{\star}_{t,T}) + \eta_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are asymptotic autocorrelation and heteroscedasticity consistent standard errors following Newey and West (1987). $t[\beta = 1]$ is the t-statistic for testing $\beta = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α	−0.0003	−0.0013	−0.0057*	−0.0176**	−0.0582**	0.0052
se(α)	(0.0002)	(0.0008)	(0.0032)	(0.0069)	(0.0269)	(0.1364)
β	−5.5010***	−5.6732***	−5.6021***	−5.5060***	−5.0384***	−0.7535
se(β)	(1.9883)	(1.9086)	(1.7643)	(1.8159)	(1.3612)	(1.2085)
$t[\beta = 1]$	[-3.27]	[-3.50]	[-3.74]	[-3.58]	[-4.44]	[-1.45]
R^2	0.0029	0.0166	0.0787	0.2097	0.4709	0.0151
CAD						
α	0.0000	0.0001	0.0002	0.0004	0.0026	0.0635
se(α)	(0.0001)	(0.0003)	(0.0015)	(0.0035)	(0.0102)	(0.0765)
β	−3.4228**	−3.4443**	−2.8355**	−2.9106***	−3.0959***	−0.4018
se(β)	(1.4524)	(1.4718)	(1.4214)	(1.0993)	(0.9108)	(1.2704)
$t[\beta = 1]$	[-3.05]	[-3.02]	[-2.70]	[-3.56]	[-4.50]	[-1.10]
R^2	0.0019	0.0091	0.0288	0.0852	0.3144	0.0065
CHF						
α	0.0002**	0.0008	0.0035	0.0098	0.032	0.1296***
se(α)	(0.0001)	(0.0006)	(0.0027)	(0.0086)	(0.0273)	(0.0423)
β	−1.4813	−1.419	−1.4412	−1.3672	−1.3929	−1.0922
se(β)	(1.1402)	(1.1567)	(1.1429)	(1.2871)	(1.0399)	(0.7152)
$t[\beta = 1]$	[-2.18]	[-2.09]	[-2.14]	[-1.84]	[-2.30]	[-2.93]
R^2	0.0004	0.0019	0.0089	0.0211	0.0736	0.0845
DEM-EUR						
α	0.0001	0.0003	0.0012	0.0032	0.0064	0.0419
se(α)	(0.0001)	(0.0005)	(0.0023)	(0.0059)	(0.0204)	(0.0768)
β	−0.6817	−0.6919	−0.8104	−1.0400	−1.6348	−0.9614
se(β)	(1.0521)	(1.0695)	(1.0568)	(1.131)	(1.1785)	(0.8931)
$t[\beta = 1]$	[-1.60]	[-1.58]	[-1.71]	[-1.80]	[-2.24]	[-2.20]
R^2	0.0001	0.0005	0.0033	0.0138	0.1035	0.0471
GBP						
α	0.0001	0.0003	0.0013	0.0041	0.0131	0.1118*
se(α)	(0.0001)	(0.0007)	(0.0031)	(0.0068)	(0.0245)	(0.0632)
β	0.2833	0.2496	0.1932	0.1842	0.2879	1.5835***
se(β)	(1.0295)	(1.1018)	(1.1073)	(1.5776)	(1.3194)	(0.4945)
$t[\beta = 1]$	[-0.70]	[-0.68]	[-0.73]	[-0.52]	[-0.54]	[1.18]
R^2	0.0000	0.0001	0.0002	0.0004	0.0036	0.2715
JPY						
α	0.0003	0.0014	0.0066*	0.0205**	0.0933***	0.1764
se(α)	(0.0002)	(0.0009)	(0.0036)	(0.0082)	(0.0155)	(0.1174)
β	−1.9643*	−1.9416	−2.0449*	−2.152**	−2.4908***	−1.0064*
se(β)	(1.1533)	(1.2303)	(1.1661)	(1.0076)	(0.7335)	(0.6056)
$t[\beta = 1]$	[-2.57]	[-2.39]	[-2.61]	[-3.13]	[-4.76]	[-3.31]
R^2	0.0007	0.0031	0.017	0.0467	0.2731	0.1331

Table 4: Yield Pricing Errors and Matching Depreciation Rates

The table reports pricing errors for domestic (US) and foreign yields as well as results for how well model implied depreciation rates match observed rates. Columns labeled "Yield Pricing Errors" report annualized root mean squared errors in basis points for the yield maturities indicated in the header. Columns labeled "Matching Depreciation Rates" report correlations of model implied and observed rates ("corr") and results of regressing the later on the former with c_0 denoting the intercept, c_1 the slope coefficient, and se(·) the respective block-bootstrapped standard errors in parentheses. R^2 is the in-sample coefficient of determination. Panel A presents results for the global model in which the international economy is driven by two domestic (common) factors and two factors per foreign country. The model is described in detail in Section *3.1*. Panel B presents results for the single-country model specification with three factors per country as described in Appendix E. The results are based on daily observations for the sample periods October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

Panel A: Global Model

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	5	4	6	17	14	11	23						
AUD	5	7	8	14	16	23	40	0.9989	-0.0000	(0.0000)	1.0142	(0.0009)	0.9979
CAD	8	10	10	16	29	43	65	0.9985	-0.0000	(0.0000)	1.0311	(0.0012)	0.9971
CHF	8	9	8	14	27	39	52	0.9002	-0.0000	(0.0000)	0.9350	(0.0099)	0.8104
DEM-EUR	10	12	12	18	37	53	71	0.8909	0.0000	(0.0000)	0.9996	(0.0110)	0.7937
GBP	10	10	10	24	38	56	84	0.9561	0.0000	(0.0000)	1.2241	(0.0105)	0.9142
JPY	6	9	11	16	23	45	75	0.9862	0.0000	(0.0000)	0.9789	(0.0035)	0.9726

Panel B: Single-Country Models and Currency Implications

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	2	3	4	5	6	6	8						
AUD	1	2	3	4	5	6	8	-0.0372	0.0000	(0.0001)	-0.0006	(0.0004)	0.0014
CAD	2	3	5	6	9	10	13	0.1022	-0.0000	(0.0001)	0.0008	(0.0002)	0.0104
CHF	2	3	4	5	7	6	8	0.0770	0.0001	(0.0001)	0.0015	(0.0004)	0.0059
DEM-EUR	2	2	4	6	7	6	8	0.0582	0.0001	(0.0001)	0.0014	(0.0005)	0.0034
GBP	2	3	4	5	8	7	10	0.0175	0.0000	(0.0001)	0.0003	(0.0004)	0.0003
JPY	1	2	3	4	6	5	7	0.0477	0.0001	(0.0001)	0.0011	(0.0004)	0.0023

Table 5: Interpretation of Latent State Variables: US Risk Factors and Carry Risk Factors

The table reports results related to the three factor rotations discussed in Section 4.3.2. For each rotation, we report the correlation (in percentage points) of the model-implied variables to the respective model-independent estimates in blocks of four columns each: the first two columns report results for the US short rate level (r_t), the slope (μ_t), and the level differential ($r_t - r_t^{\star i}$) implied from the model. V_t and U_t are the corresponding quadratic variations. In the rows, L_t denotes the model-free estimate of the US short rate level, Sl_t the estimate for the slope, and $L_t - L_t^{\star i}$ for the short rate differential. $QV_t[\cdot]$ denotes the respective quadratic variation. In the last two rows and columns we report correlations to $\mathbb{Q}$-expected depreciation ($\mathbb{E}_t^{\mathbb{Q}}[ds]$) and to the model-implied variance of the exchange rate ($QV_t[ds]$). The results are based on parameter and states variable estimates of the model using daily data from October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	Rotation 1				Rotation 2				Rotation 3					
	r_t	μ_t	V_t	U_t	r_t	$r_t - r_t^{\star i}$	V_t	U_t	$r_t - r_t^{\star i}$	r_t	V_t	U_t	$\mathbb{E}_t^{\mathbb{Q}}[ds]$	$QV_t[ds]$
AUD														
L_t	99.6	−56.9	35.7	35.7	99.6	−73.9	35.7	35.7	84.6	26.1	36.0	48.4	84.6	51.0
Sl_t	−8.7	48.8	45.2	45.2									−5.2	27.8
$L_t - L_t^{\star i}$					84.4	−34.7	23.9	23.9	99.0	9.3	23.8	16.9	99.0	13.3
$QV_t[L]$	29.5	6.0	40.3	40.3	29.5	15.1	40.3	40.3	43.9	−6.3	40.1	24.9	43.9	16.2
$QV_t[Sl]$	45.6	0.4	51.5	51.5									41.6	51.8
$QV_t[L - L^{\star i}]$					45.1	−13.4	3.5	3.5	60.8	−9.0	3.3	−5.0	60.8	−8.5
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	85.3	−53.9	24.8	24.8	85.3	−34.7	24.8	24.8	100.0	4.3	24.7	18.5	100.0	15.1
$QV_t[ds]$	52.8	27.3	82.3	82.3	52.8	−41.1	82.3	82.4	15.2	4.2	82.9	98.6	15.1	100.0
CAD														
L_t	99.6	−53.4	31.4	31.4	99.6	−83.0	31.4	19.4	62.7	26.0	−28.8	−30.4	62.7	−30.4
Sl_t	−9.8	55.8	51.8	51.8									6.1	−4.1
$L_t - L_t^{\star i}$					65.1	−21.5	21.3	−11.6	96.1	11.5	−87.2	−88.0	96.2	−88.0
$QV_t[L]$	31.2	7.5	36.7	36.7	31.2	−20.7	36.7	35.7	11.8	22.1	−0.4	−2.5	11.8	−2.6
$QV_t[Sl]$	50.5	2.6	49.1	49.1									15.6	3.6
$QV_t[L - L^{\star i}]$					33.3	−48.1	−1.9	6.6	−5.6	17.3	23.3	23.3	−5.7	23.3
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	64.2	−31.9	23.0	23.0	64.2	−17.3	23.0	−10.5	100.0	−1.4	−88.5	−89.4	100.0	−89.4
$QV_t[ds]$	−31.2	14.9	−11.8	−11.8	−31.2	−15.7	−11.8	25.3	−89.2	−15.7	99.8	100.0	−89.4	100.0
CHF														
L_t	99.6	−43.0	43.6	43.6	99.6	−69.3	43.6	45.9	19.8	40.7	43.9	44.1	19.8	44.1
Sl_t	−17.2	49.7	34.3	34.3									22.1	−29.0
$L_t - L_t^{\star i}$					27.7	51.1	−40.1	−74.2	99.2	−78.5	−76.7	−76.6	99.2	−76.6
$QV_t[L]$	23.8	29.8	50.0	50.0	23.8	−63.3	50.0	69.3	−51.3	69.0	69.0	69.1	−51.3	69.1
$QV_t[Sl]$	23.1	26.4	45.8	45.8									−45.6	62.7
$QV_t[L - L^{\star i}]$					37.5	−79.3	52.2	78.9	−53.3	78.4	79.5	79.5	−53.3	79.5
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	25.0	−62.7	−40.4	−40.4	25.0	54.5	−40.4	−76.3	100.0	−80.7	−79.1	−79.0	100.0	−78.9
$QV_t[ds]$	39.6	35.0	68.9	68.9	39.6	−91.8	68.9	99.4	−78.9	99.8	100.0	100.0	−78.9	100.0
DEM-EUR														
L_t	99.6	−43.0	43.6	43.6	99.6	−59.3	43.6	75.4	40.1	−5.3	75.4	75.4	40.2	75.0
Sl_t	−17.2	49.7	34.3	34.3									18.3	−23.6
$L_t - L_t^{\star i}$					48.4	39.7	−21.3	−23.7	97.3	−10.0	−23.7	−23.7	97.8	−23.8
$QV_t[L]$	23.8	29.8	50.0	50.0	23.8	−60.2	50.0	65.3	−44.0	6.0	65.3	65.4	−44.2	65.5
$QV_t[Sl]$	23.1	26.4	45.8	45.8									−39.6	60.4
$QV_t[L - L^{\star i}]$					8.4	−63.7	46.2	62.3	−60.9	12.4	62.3	62.3	−61.0	62.4
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	45.0	−61.8	−22.2	−22.2	45.0	46.2	−22.2	−26.8	99.9	−24.1	−26.8	−26.8	100.0	−26.9
$QV_t[ds]$	72.2	11.7	74.1	74.1	72.2	−87.6	74.1	100.0	−26.5	−2.0	100.0	100.0	−26.9	100.0
GBP														
L_t	99.6	−43.0	43.6	43.6	99.6	−81.3	43.6	48.2	−11.4	8.5	47.1	47.1	−11.4	47.1
Sl_t	−17.2	49.7	34.3	34.3									45.5	−40.8
$L_t - L_t^{\star i}$					−6.9	62.5	−36.8	−90.8	98.0	−6.7	−91.8	−91.9	98.2	−91.8
$QV_t[L]$	23.8	29.8	50.0	50.0	23.8	−48.3	50.0	67.4	−52.1	7.4	66.2	66.1	−52.2	66.2
$QV_t[Sl]$	23.1	26.4	45.8	45.8									−44.2	57.5
$QV_t[L - L^{\star i}]$					3.3	−22.2	35.3	45.1	−39.2	4.2	44.1	44.0	−39.3	44.1
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	−5.3	−28.9	−33.2	−33.2	−5.3	63.4	−33.2	−90.7	99.9	−13.3	−92.0	−92.0	100.0	−92.0
$QV_t[ds]$	42.2	18.8	55.1	55.1	42.2	−83.6	55.1	99.8	−91.8	8.4	100.0	100.0	−92.0	100.0
JPY														
L_t	99.6	−43.0	43.6	43.6	99.6	−66.3	43.6	46.5	32.2	19.8	56.9	56.8	28.0	56.8
Sl_t	−17.2	49.7	34.3	34.3									21.3	−18.2
$L_t - L_t^{\star i}$					34.6	47.5	−34.3	−38.5	99.4	−60.1	−59.2	−60.0	99.2	−58.9
$QV_t[L]$	23.8	29.8	50.0	50.0	23.8	−68.5	50.0	54.1	−50.1	64.6	73.5	73.9	−51.3	73.3
$QV_t[Sl]$	23.1	26.4	45.8	45.8									−46.3	67.3
$QV_t[L - L^{\star i}]$					27.5	−73.2	53.1	57.5	−51.3	68.7	78.0	78.5	−52.4	77.8
$\mathbb{E}_t^{\mathbb{Q}}[ds]$	33.1	−61.8	−32.6	−32.6	33.1	50.0	−32.6	−37.1	99.5	−57.9	−60.2	−61.3	100.0	−59.9
$QV_t[ds]$	53.6	32.6	78.7	78.7	53.6	−90.0	78.7	83.6	−56.6	65.9	100.0	99.8	−59.9	100.0

Table 6: Fama Conditions

The table shows the relevant variance ratios and correlations to assess the Fama-conditions in Eq. (3). Rows labeled "Variance ratios" report the variance of the model implied risk premium, $\widehat{\lambda}_{t,T}$, divided by the variance of the model expected depreciation, $\Delta\widehat{s}_{t,T}$. Rows labeled "Correlations" report the correlation between $\widehat{\lambda}_{t,T}$ and $\Delta\widehat{s}_{t,T}$. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
Variance ratios	1.2224	1.2369	1.3016	1.3851	1.4874	1.4208
Correlations	−0.9935	−0.9935	−0.9936	−0.9947	−0.9978	−0.9918
CAD						
Variance ratios	1.2181	1.2505	1.3619	1.4357	1.4390	1.3743
Correlations	−0.9907	−0.9905	−0.9905	−0.9913	−0.9904	−0.9851
CHF						
Variance ratios	1.0222	1.0705	1.5664	2.1308	2.1822	2.1071
Correlations	−0.9982	−0.9936	−0.9686	−0.9705	−0.9702	−0.9606
DEM-EUR						
Variance ratios	1.0220	1.0715	1.4816	1.8508	1.8973	1.8629
Correlations	−0.9987	−0.9947	−0.9754	−0.9731	−0.9734	−0.9701
GBP						
Variance ratios	0.7870	0.6367	0.5861	0.5861	0.6054	0.6712
Correlations	−0.9341	−0.8796	−0.8459	−0.8501	−0.8842	−0.9339
JPY						
Variance ratios	1.3072	1.3721	1.6790	2.0476	2.1191	2.4140
Correlations	−0.9736	−0.9711	−0.9654	−0.9717	−0.9783	−0.9842

Table 7: Regressions of Excess Returns on Expected Excess Returns

The table shows the results from estimating, by ordinary least squares, the regression (23), $ER_{t,T} = \alpha' + \beta' \widehat{ER}_{t,T} + \eta'_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are block-bootstrapped standard errors. $t[\beta' = 1]$ is the t-statistic for testing $\beta' = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α'	0.0001	0.0004	0.0018	0.0031	0.0038	0.0207
se(α')	(0.0001)	(0.0006)	(0.0023)	(0.0061)	(0.0217)	(0.0832)
β'	0.6187*	0.6346*	0.6768*	1.0780***	1.2281***	0.7597**
se(β')	(0.3524)	(0.3366)	(0.3681)	(0.3195)	(0.2913)	(0.3101)
$t[\beta' = 1]$	[-1.08]	[-1.09]	[-0.88]	[0.24]	[0.78]	[-0.78]
R^2	0.0018	0.0099	0.0463	0.2474	0.5875	0.3771
CAD						
α'	0.0000	0.0001	0.0001	−0.0007	−0.0016	0.0078
se(α')	(0.0001)	(0.0003)	(0.0012)	(0.0033)	(0.0078)	(0.0331)
β'	0.6676**	0.6680**	0.6898**	0.9071***	1.0110***	0.9210***
se(β')	(0.2636)	(0.2766)	(0.2721)	(0.2737)	(0.1753)	(0.2053)
$t[\beta' = 1]$	[-1.26]	[-1.20]	[-1.14]	[-0.34]	[0.06]	[-0.38]
R^2	0.0026	0.0120	0.0484	0.1816	0.5945	0.6010
CHF						
α'	0.0000	0.0001	0.0003	0.0015	0.0008	0.0046
se(α')	(0.0001)	(0.0006)	(0.0024)	(0.0067)	(0.0202)	(0.0388)
β'	0.5026***	0.5829***	0.9802***	1.1423***	1.0699***	0.8785***
se(β')	(0.0819)	(0.1147)	(0.2668)	(0.3322)	(0.3790)	(0.2874)
$t[\beta' = 1]$	[-6.07]	[-3.64]	[-0.07]	[0.43]	[0.18]	[-0.42]
R^2	0.0131	0.0247	0.0491	0.1012	0.2539	0.3259
DEM-EUR						
α'	−0.0000	0.0003	0.0014	0.0040	0.0080	0.0072
se(α')	(0.0001)	(0.0006)	(0.0023)	(0.0061)	(0.0188)	(0.0512)
β'	0.7825***	0.3900***	0.5871**	0.9673***	1.0513***	0.7828***
se(β')	(0.0953)	(0.1392)	(0.2344)	(0.3390)	(0.3567)	(0.2907)
$t[\beta' = 1]$	[-2.28]	[-4.38]	[-1.76]	[-0.10]	[0.14]	[-0.75]
R^2	0.0476	0.0146	0.0214	0.0917	0.3039	0.3041
GBP						
α'	0.0002**	0.0007	0.0027	0.0078	0.0220	0.0204
se(α')	(0.0001)	(0.0005)	(0.0025)	(0.0072)	(0.0205)	(0.0387)
β'	−0.5997	0.0495	0.3372	0.4070	0.4736	0.7633***
se(β')	(0.7242)	(1.0026)	(1.0677)	(1.1015)	(0.7624)	(0.2716)
$t[\beta' = 1]$	[-2.21]	[-0.95]	[-0.62]	[-0.54]	[-0.69]	[-0.87]
R^2	0.0005	0.0000	0.0010	0.0040	0.0249	0.3384
JPY						
α'	−0.0000	−0.0001	−0.0001	−0.0004	0.0010	−0.0029
se(α')	(0.0002)	(0.0007)	(0.0025)	(0.0063)	(0.0211)	(0.0439)
β'	−0.3499	0.1139	0.5334*	0.8291**	1.1093***	0.9443***
se(β')	(0.3793)	(0.3756)	(0.3239)	(0.3676)	(0.3502)	(0.1992)
$t[\beta' = 1]$	[-3.56]	[-2.36]	[-1.44]	[-0.46]	[0.31]	[-0.28]
R^2	0.0004	0.0002	0.0108	0.0496	0.3200	0.6187

Table 8: Ability to Predict Excess Returns

The table reports results related to the predictive ability of the model as compared to the UIP and RW benchmarks. Hit-ratios (HR) are calculated as the proportion of times the sign of the excess return is correctly predicted by the model. $R2 = 1 - MSE_M/MSE_B$ where MSE_M denotes the mean squared prediction error of the model and MSE_B that of the benchmark. CW and GW denote the test-statistics of Clark and West (2007) and Giacomini and White (2006) as described in Section *3.3*. The one-sided p-values of the test-statistics in square brackets are obtained from the block bootstrap procedure described in Appendix F which accounts for autocorrelation and heteroscedasticity. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	Model vs. UIP						Model vs. RW					
	1d	1w	1m	3m	1y	4y	1d	1w	1m	3m	1y	4y
AUD												
HR	0.5372	0.5560	0.6000	0.7667	0.8250	0.7083	0.5372	0.5560	0.6000	0.7667	0.8250	0.7083
$R2$	0.0019	0.0106	0.0497	0.2515	0.5922	0.4225	0.0007	0.0037	0.0176	0.1849	0.5029	0.3476
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.173]	[0.129]	[0.052]	[<0.01]	[<0.01]	[<0.01]	[0.265]	[0.201]	[0.121]	[0.013]	[<0.01]	[<0.01]
CAD												
HR	0.5323	0.5535	0.5515	0.5882	0.7426	0.6324	0.5323	0.5535	0.5515	0.5882	0.7426	0.6324
$R2$	0.0027	0.0122	0.0490	0.1830	0.6022	0.6682	0.0014	0.0061	0.0261	0.1265	0.5069	0.6342
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.025]	[0.034]	[0.039]	[0.014]	[<0.01]	[<0.01]
p-value[GW]	[0.122]	[0.208]	[0.234]	[0.063]	[0.013]	[<0.01]	[0.238]	[0.234]	[0.327]	[0.115]	[0.037]	[<0.01]
CHF												
HR	0.5268	0.5461	0.5889	0.6500	0.8000	0.7611	0.5268	0.5461	0.5889	0.6500	0.8000	0.7611
$R2$	0.0132	0.0249	0.0501	0.1031	0.2540	0.3356	0.0125	0.0220	0.0371	0.0719	0.1601	0.2277
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[0.054]	[0.072]	[0.033]	[0.013]	[<0.01]	[<0.01]	[0.070]	[0.135]	[0.049]	[0.041]	[<0.01]
DEM-EUR												
HR	0.5759	0.5626	0.5556	0.6222	0.7889	0.7556	0.5759	0.5626	0.5556	0.6222	0.7889	0.7556
$R2$	0.0477	0.0153	0.0245	0.0977	0.3076	0.3072	0.0472	0.0125	0.0108	0.0607	0.1929	0.2153
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.076]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[<0.01]	[0.174]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.027]	[0.255]	[0.017]	[0.018]	[<0.01]
GBP												
HR	0.5187	0.5424	0.5333	0.6111	0.5944	0.6778	0.5187	0.5424	0.5333	0.6111	0.5944	0.6778
$R2$	0.0011	0.0025	0.0122	0.0354	0.1145	0.5413	0.0005	-0.0003	-0.0007	-0.0001	0.0137	0.5118
p-value[CW]	[0.722]	[0.206]	[0.114]	[0.054]	[0.024]	[<0.01]	[0.724]	[0.199]	[0.212]	[0.116]	[<0.01]	[<0.01]
p-value[GW]	[0.074]	[0.389]	[0.322]	[0.146]	[0.094]	[<0.01]	[0.064]	[0.336]	[0.419]	[0.194]	[0.052]	[<0.01]
JPY												
HR	0.5071	0.5373	0.5611	0.6111	0.7278	0.9500	0.5071	0.5373	0.5611	0.6111	0.7278	0.9500
$R2$	0.0004	0.0002	0.0109	0.0501	0.3235	0.6802	-0.0004	-0.0033	-0.0062	0.0068	0.1731	0.4972
p-value[CW]	[0.925]	[0.545]	[0.075]	[<0.01]	[<0.01]	[<0.01]	[0.997]	[0.882]	[0.462]	[0.081]	[<0.01]	[0.023]
p-value[GW]	[0.354]	[0.137]	[0.326]	[0.118]	[0.017]	[<0.01]	[0.377]	[0.117]	[0.300]	[0.276]	[0.035]	[0.014]

Table 9: Decomposing Foreign Exchange Risk Premiums

This table reports means and standard deviations (in parentheses) of annualized foreign exchange risk premiums and their components, i.e. the pure currency risk component and the component that accounts for the fact that interest rates are stochastic; for the decomposition see Section *2.2*, in particular Eq. (8). The descriptives are calculated from daily model estimates of the risk premiums. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

		1 day	1 week	1 month	3 months	1 year	4 years
AUD							
Risk Premium	Mean	0.0038	0.0030	0.0004	−0.0037	−0.0090	−0.0185
	Std Dev	(0.0072)	(0.0158)	(0.0299)	(0.0472)	(0.0811)	(0.1086)
- Pure currency risk	Mean	−0.0020	−0.0028	−0.0052	−0.0093	−0.0147	−0.0239
	Std Dev	(0.0072)	(0.0158)	(0.0299)	(0.0472)	(0.0811)	(0.1086)
- Stochastic rates	Mean	0.0058	0.0058	0.0056	0.0056	0.0057	0.0054
	Std Dev	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)
CAD							
Risk Premium	Mean	−0.0036	−0.0045	−0.0068	−0.0089	−0.0109	−0.0185
	Std Dev	(0.0046)	(0.0098)	(0.0177)	(0.0285)	(0.0509)	(0.0706)
- Pure currency risk	Mean	−0.0053	−0.0063	−0.0084	−0.0105	−0.0127	−0.0206
	Std Dev	(0.0046)	(0.0098)	(0.0178)	(0.0286)	(0.0512)	(0.0708)
- Stochastic rates	Mean	0.0017	0.0017	0.0017	0.0017	0.0018	0.0020
	Std Dev	(0.0000)	(0.0001)	(0.0001)	(0.0002)	(0.0004)	(0.0006)
CHF							
Risk Premium	Mean	−0.0051	−0.0051	−0.0045	−0.0036	−0.0001	0.0081
	Std Dev	(0.0259)	(0.0303)	(0.0244)	(0.0328)	(0.0556)	(0.0670)
- Pure currency risk	Mean	−0.0121	−0.0120	−0.0113	−0.0104	−0.0072	0.0005
	Std Dev	(0.0259)	(0.0304)	(0.0246)	(0.0332)	(0.0564)	(0.0682)
- Stochastic rates	Mean	0.0070	0.0070	0.0067	0.0068	0.0071	0.0076
	Std Dev	(0.0001)	(0.0002)	(0.0004)	(0.0007)	(0.0014)	(0.0026)
DEM-EUR							
Risk Premium	Mean	−0.0260	−0.0247	−0.0199	−0.0138	−0.0066	−0.0030
	Std Dev	(0.0123)	(0.0261)	(0.0437)	(0.0517)	(0.0620)	(0.0785)
- Pure currency risk	Mean	−0.0330	−0.0317	−0.0267	−0.0208	−0.0149	−0.0144
	Std Dev	(0.0124)	(0.0263)	(0.0440)	(0.0523)	(0.0630)	(0.0790)
- Stochastic rates	Mean	0.0070	0.0070	0.0068	0.0070	0.0083	0.0114
	Std Dev	(0.0002)	(0.0004)	(0.0009)	(0.0015)	(0.0033)	(0.0071)
GBP							
Risk Premium	Mean	−0.0116	−0.0114	−0.0111	−0.0113	−0.0132	−0.0199
	Std Dev	(0.0034)	(0.0051)	(0.0091)	(0.0154)	(0.0292)	(0.0458)
- Pure currency risk	Mean	−0.0159	−0.0158	−0.0153	−0.0155	−0.0173	−0.0237
	Std Dev	(0.0034)	(0.0049)	(0.0088)	(0.0149)	(0.0282)	(0.0441)
- Stochastic rates	Mean	0.0044	0.0044	0.0042	0.0042	0.0042	0.0038
	Std Dev	(0.0001)	(0.0003)	(0.0006)	(0.0010)	(0.0018)	(0.0023)
JPY							
Risk Premium	Mean	0.0067	0.0062	0.0046	0.0040	0.0086	0.0235
	Std Dev	(0.0061)	(0.0128)	(0.0217)	(0.0330)	(0.0604)	(0.0862)
- Pure currency risk	Mean	0.0009	0.0003	−0.0011	−0.0017	0.0026	0.0169
	Std Dev	(0.0061)	(0.0128)	(0.0217)	(0.0330)	(0.0605)	(0.0872)
- Stochastic rates	Mean	0.0058	0.0058	0.0057	0.0057	0.0060	0.0066
	Std Dev	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0002)	(0.0011)

Table 10: Correlations of Expected Excess Returns with Financial and Fundamental Variables

The table presents contemporaneous correlations of expected excess returns with the VIX signed by the yield differential ($sVIX_t$), the 1-year log changes in US industrial production (ΔIP_t) and US narrow money supply (ΔNM_t), the observable fundamentals, $\Delta OF_t = (\Delta NM_t - \Delta NM_t^\star) - (\Delta IP_t - \Delta IP_t^\star)$, and the 1-year log change in CPI deflated private consumption per capita in the US ($s\Delta CO_t$). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The significance is judged by block-bootstrapped standard errors which are not reported. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY. Analysis involving the VIX start in January 1990.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
$sVIX_t$	−0.5352***	−0.5466***	−0.5342***	−0.7128***	−0.7847***	−0.7662***
ΔIP_t			−0.4309***	−0.7577***	−0.8388***	−0.8994***
ΔNM_t			0.3049	0.3931	0.5490*	0.6715**
ΔCO_t				−0.6895**	−0.7655**	−0.7308**
ΔOF_t				0.7116***	0.7854***	0.8226***
CAD						
$sVIX_t$	−0.6189***	−0.6364***	−0.6700***	−0.7440***	−0.7715***	−0.7260***
ΔIP_t			−0.5797***	−0.8712***	−0.9218***	−0.9219***
ΔNM_t			0.6162***	0.6810***	0.7595***	0.7128***
$s\Delta CO_t$				−0.7012**	−0.7049**	−0.6531**
ΔOF_t			0.4899***	0.7597***	0.7726***	0.7186***
CHF						
$sVIX_t$	−0.1622***	−0.2541***	−0.5097***	−0.6441**	−0.5946*	−0.4782
ΔIP_t			−0.2615*	−0.6980***	−0.7723***	−0.8472***
ΔNM_t			0.5508***	0.8043***	0.8577***	0.8818***
$s\Delta CO_t$				−0.5636**	−0.5391*	−0.4746
ΔOF_t				0.4849*	0.5200**	0.4428*
DEM-EUR						
$sVIX_t$	−0.1659***	−0.2662***	−0.5663***	−0.7256***	−0.7634***	−0.7781***
ΔIP_t			−0.3001**	−0.7830***	−0.8282***	−0.8556***
ΔNM_t			0.6368***	0.8100***	0.8528***	0.8449***
$s\Delta CO_t$				−0.5931**	−0.6321***	−0.6510***
ΔOF_t			0.4702***	0.6932***	0.7416***	0.7454***
GBP						
$sVIX_t$	−0.0471	−0.1196	−0.1333	−0.1880	−0.1833	−0.1801
ΔIP_t			−0.2065	−0.5651**	−0.5126*	−0.4030
ΔNM_t			0.5215***	0.5107***	0.4568**	0.3275
$s\Delta CO_t$				−0.1550	−0.1661	−0.1911
ΔOF_t			0.5462***	0.5004**	0.4447*	0.3120
JPY						
$sVIX_t$	−0.5421***	−0.5885***	−0.6650***	−0.7199**	−0.7743**	−0.7757**
ΔIP_t			−0.3892**	−0.6284***	−0.6128***	−0.5946***
ΔNM_t			0.5184***	0.6405***	0.6057***	0.5637**
$s\Delta CO_t$				−0.7788***	−0.8178***	−0.8273***
ΔOF_t			0.5246***	0.8289***	0.8502***	0.8506***

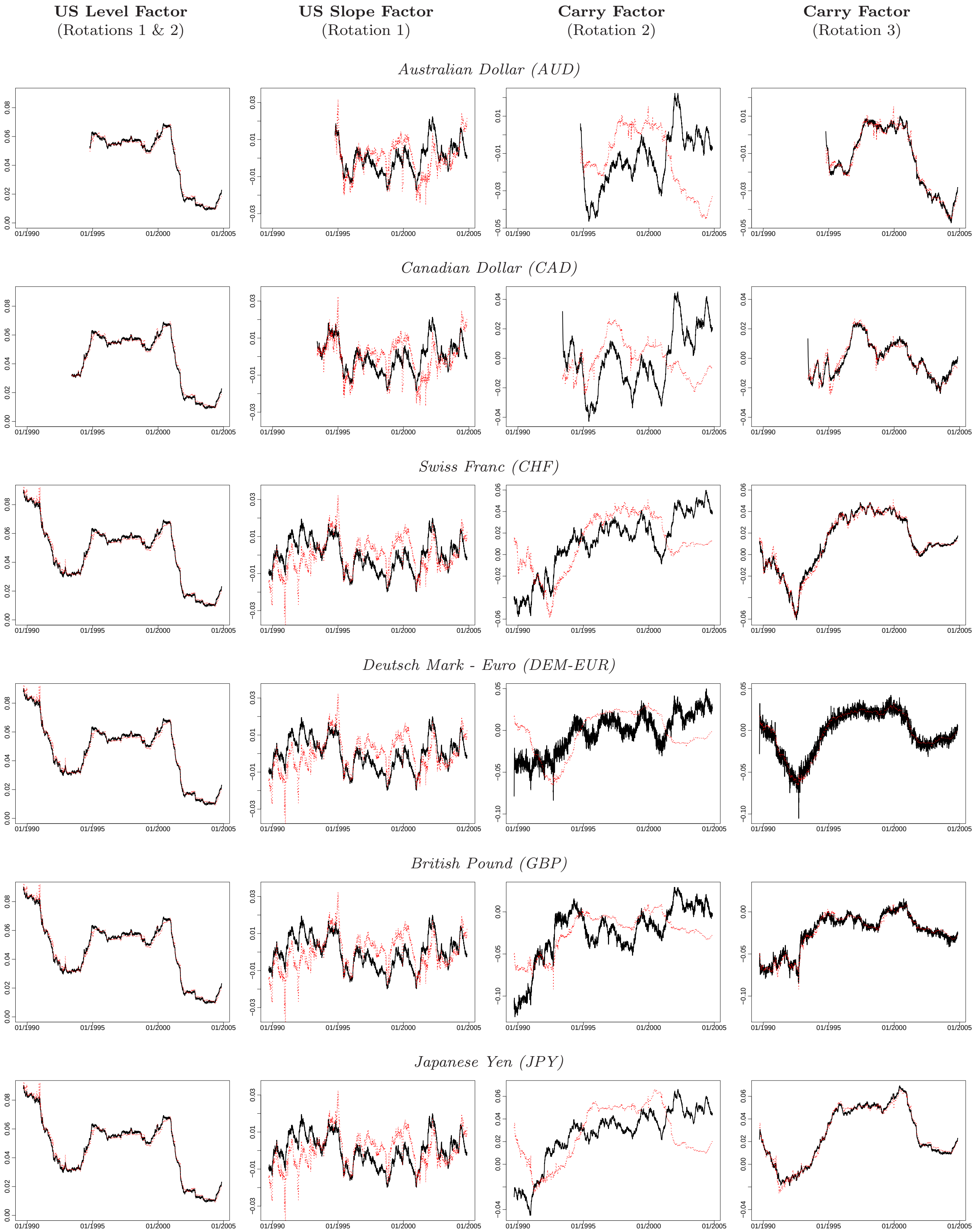
Table 11: Regressions of Expected Excess Returns on Financial and Fundamental Variables

The table presents results of regressing expected excess returns on the proxies for global risk (VIX signed with the yield differential, $sVIX_t$), exchange rate fundamentals (observable fundamentals, $\Delta OF_t = (\Delta NM_t - \Delta NM_t^{\star}) - (\Delta IP_t - \Delta IP_t^{\star})$), US consumption growth ($s\Delta CO_t$), and combinations thereof. Numbers in parentheses are block bootstrapped standard errors. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on quarterly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY. Analysis involving the VIX start in January 1990.

	Global Risk				FX Fundamentals			Global Risk and FX Fundamentals						Cons. Growth		Cons. Growth and FX Fundamentals			
	1 day	1 month	3 months	1 year	1 month	3 months	1 year	1 month		3 months		1 year		3 months	1 year	3 months		1 year	
	$sVIX_t$	$sVIX_t$	$sVIX_t$	$sVIX_t$	ΔOF_t	ΔOF_t	ΔOF_t	$sVIX_t$	ΔOF_t	$sVIX_t$	ΔOF_t	$sVIX_t$	ΔOF_t	$s\Delta CO_t$	$s\Delta CO_t$	$s\Delta CO_t$	ΔOF_t	$s\Delta CO_t$	ΔOF_t
AUD																			
coeff	−0.0011***	−0.0231***	−0.0776***	−0.2844***		0.1383***	0.5083***			−0.0478***	0.0847***	−0.1745***	0.3127***	−0.2839***	−1.0491***	−0.1853***	0.0959***	−0.6890***	0.3504***
se	(0.0002)	(0.0055)	(0.0146)	(0.0572)		(0.0370)	(0.1204)			(0.0144)	(0.0289)	(0.0391)	(0.0801)	(0.0537)	(0.1971)	(0.0609)	(0.0245)	(0.1381)	(0.0707)
R^2	0.2864	0.2853	0.5081	0.6158		0.5064	0.6168			0.6233	0.6233	0.7573	0.7573	0.4754	0.5860	0.6613	0.6613	0.8100	0.8100
CAD																			
coeff	−0.0008***	−0.0171***	−0.0492***	−0.1786***	0.0505***	0.1746***	0.6214***	−0.0144	0.0256***	−0.0288***	0.1101***	−0.1083***	0.3788***	−0.1766***	−0.6212***	−0.1046**	0.1240***	−0.3622**	0.4463***
se	(0.0002)	(0.0033)	(0.0112)	(0.0419)	(0.0150)	(0.0510)	(0.1897)	(0.0105)	(0.0030)	(0.0085)	(0.0355)	(0.0328)	(0.1338)	(0.0506)	(0.1864)	(0.0414)	(0.0361)	(0.1753)	(0.1281)
R^2	0.3830	0.4489	0.5535	0.5953	0.2400	0.5771	0.5969	0.4990	0.4990	0.6877	0.6877	0.7249	0.7249	0.4917	0.4969	0.7013	0.7013	0.7185	0.7185
CHF																			
coeff	−0.0015***	−0.0201***	−0.0616**	−0.1865		0.0669**	0.2353**			−0.0500**	0.0333	−0.1345*	0.1496*	−0.2676***	−0.8397**	−0.2120**	0.0446*	−0.6288*	0.1691**
se	(0.0005)	(0.0054)	(0.0255)	(0.1147)		(0.0327)	(0.1041)			(0.0219)	(0.0266)	(0.0773)	(0.0817)	(0.0965)	(0.3663)	(0.1032)	(0.0246)	(0.3698)	(0.0769)
R^2	0.0263	0.2597	0.4148	0.3536		0.2352	0.2704			0.4547	0.4547	0.4285	0.4285	0.3176	0.2906	0.4084	0.4084	0.4120	0.4120
DEM-EUR																			
coeff	−0.0014***	−0.0211***	−0.0614***	−0.2197***	0.0657***	0.1316***	0.4789***	−0.0156	0.0291***	−0.0367**	0.0658**	−0.1222**	0.2597***	−0.2116***	−0.7669***	−0.0897	0.1010***	−0.3214	0.3690***
se	(0.0004)	(0.0045)	(0.0112)	(0.0456)	(0.0137)	(0.0240)	(0.0728)	(0.0165)	(0.0056)	(0.0150)	(0.0331)	(0.0486)	(0.0931)	(0.0583)	(0.2042)	(0.0644)	(0.0295)	(0.1955)	(0.0823)
R^2	0.0275	0.3207	0.5265	0.5827	0.2211	0.4805	0.5500	0.3469	0.3469	0.5652	0.5652	0.6348	0.6348	0.3517	0.3995	0.5177	0.5177	0.5912	0.5912
GBP																			
coeff	−0.0001	−0.0026	−0.0103	−0.0372	0.0155***	0.0368***	0.1226**	−0.0019	0.0140***	−0.0075	0.0309**	−0.0284	0.0979*	−0.0288	−0.1158	−0.0366	0.0380***	−0.1418	0.1272**
se	(0.0002)	(0.0030)	(0.0164)	(0.0609)	(0.0032)	(0.0142)	(0.0525)	(0.0029)	(0.0028)	(0.0133)	(0.0129)	(0.0542)	(0.0509)	(0.0349)	(0.1114)	(0.0354)	(0.0140)	(0.1396)	(0.0565)
R^2	0.0022	0.0178	0.0354	0.0336	0.2983	0.2504	0.1977	0.2675	0.2675	0.2272	0.2272	0.1736	0.1736	0.0240	0.0276	0.2888	0.2888	0.2388	0.2388
JPY																			
coeff	−0.0014***	−0.0292***	−0.0819**	−0.3059**	0.0385***	0.0989***	0.3579***	−0.0232***	0.0184***	−0.0361*	0.0765***	−0.1568**	0.2487***	−0.4807***	−1.7819***	−0.2543*	0.0666*	−0.9935**	0.2318*
se	(0.0003)	(0.0058)	(0.0395)	(0.1309)	(0.0112)	(0.0308)	(0.0989)	(0.0085)	(0.0067)	(0.0202)	(0.0289)	(0.0678)	(0.0884)	(0.1279)	(0.4405)	(0.1543)	(0.0378)	(0.4929)	(0.1206)
R^2	0.2938	0.4423	0.5182	0.5995	0.2752	0.6871	0.7228	0.4911	0.4911	0.7451	0.7451	0.7985	0.7985	0.6066	0.6687	0.7836	0.7836	0.8409	0.8409

Figure 1: Interpretation of Latent State Variables: US Risk Factors and Carry Risk Factors

The figure plots the US risk factors and Carry risk factors as described in Section *4.3.2*. The solid (black) lines represent model-implied estimates obtained through factor rotations. The dashed lines (red) are the corresponding model-independent estimates. The first column plots the US short rate level from Rotations 1 and 2, the second the US slope from Rotation 1, the third the carry factor from Rotation 2, and the fourth the carry factor from Rotation 3. Estimations are based on daily data from October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.



Internet Appendix for

"Properties of Foreign Exchange Risk Premiums" (not for publication)

This separate Internet Appendix first reports and discusses detailed empirical results related to parameter estimations. We then present a number of Tables which are discussed and referenced in the main text but are not included in the paper.

AA Details related to model estimation results

We present the parameter estimates for the global model of the US and the six foreign countries estimated using the zero yields of the two countries and the respective spot exchange rate applying the procedure described in Section *3.2*. Table A.1 reports point estimates and corresponding 95 percent confidence intervals for the US parameters in Panel A and for the foreign economies in Panel B. Point estimates are computed as the draw from the posterior distribution with minimal L1 distance to the other draws. Confidence intervals are computed from the empirical posterior distribution. All confidence intervals are fairly tight, only for 18 of the 182 parameters we report the confidence interval includes zero and most of these are significant at the 10 percent level.

We also check whether the properties of model-implied US bond risk premiums are consistent with those reported in other studies. Duffee (2002) demonstrates that affine term structure models can replicate observed term structure characteristics only if the specification of the market price of risk is flexible enough. A first check reveals that the risk premiums implied by the model change signs and are highly variable, a necessary condition to match the observed data. Following Duffee (2002), we assess the specification of the market price of risk by analyzing whether the model is capable to replicate the empirical relation between expected returns and the slope of the yield curve. We generate yield predictions for maturities of 6 months, 2 years, and 4 years (the longest maturity in our data set) at prediction horizons of 3 months, 6 months, and 1 year, and regress the prediction errors on the slope defined as the 4-year minus the 3-month yield. The t-statistics are all small and insignificant (ranging from -0.20 to -1.24) which implies that the model captures the information contained in the slope. Overall, the results suggest that the market price of risk specification is indeed consistent with the prevailing literature on US term structure risk premiums.

BB Comparison of model parameters for estimations conditioning on information in currency options

To take another close look at the effect of conditioning on MFIV, we compare parameters and state variables of our baseline estimation to the estimation that requires the model to match MFIV. Bayesian methodology treats the latent state variables as free parameters. Consequently the state variable estimates can be different for the estimations with and without MFIV. For a meaningful comparison we therefore apply the third rotation described in Section *4.3.2*, where the international economy is driven by the carry factor (i.e. the interest rate differential), the level of the domestic short rate, and the quadratic variations of both. This allows us to compare the rotated parameters, as calculated in Appendix C, for the two estimation strategies, because the factors and their parameters then have the same economic interpretation.

For the comparison, we use the posterior draws from the MCMC estimations and consider the joint distribution of all rotated parameters. Tables A.10 and A.11 report point estimates and confidence intervals for the parameters of the estimations with and without information in currency options, and Table A.12 presents results for parameter comparisons. We report quantiles of the marginal distributions of the parameters as descriptives and use multiple-testing procedures to compare parameters.[31] We first test whether the parameters of the two estimations are different by calculating empirical p-values for each parameter and subsequently control for the dependency of these tests using conventional Bonferroni corrections and a (more powerful) procedure controlling for false discovery rates (FDR); for both see Benjamini and Hochberg (1995). The results in Table A.12 report whether parameters are significantly different at the 1%, 5%, or 10% level using Bonferroni

[31] We apply multiple-testing procedures to test for equality of parameters across estimations because the notion of a multivariate quantile is subject to current statistical research (see Hallin et al., 2010, for a recent advance); for a survey see the article by Serfling (2002).

and FDR corrections, indicated by bbb, bb, or b, and fff, ff, or f, respectively. We find that for the Bonferroni test 17 of the 240 parameters are significantly different, for the FDR corrections two more parameters are different across estimations with and without MFIV at conventional levels of significance. These results suggests that 7% to 8% of the parameters significantly change once we condition on MFIV. Taking a closer look reveals some interesting observations. First, most of these differences (7 parameters) are found for the JPY estimations. Second, as one would expect, most of the differences in parameters are associated with the processes for quadratic variations (rotated state variables 1 and 2). Third, most of the differences do not appear to be quantitatively important (are economically small) when comparing the respective values in Tables A.10 and A.11.

Overall, these findings suggest that conditioning on MFIV does not have a material effect on the estimation results and the argument that differences are very small in economic terms is supported by the fact the empirical model evaluation results reported in Section *5.2* are qualitatively identical to those above and quantitatively very similar for both estimation strategies, perhaps with the exception of the model for the JPY.

Table A.1: Model Parameters

The table shows parameter estimates for our data set. Point estimates are computed as the draw from the posterior distribution with minimal L1 distance to the other draws. Confidence intervals are computed from the empirical posterior distribution.

Panel A: Domestic (US) Parameters

	ζ	β	$a_1^{\mathbb{P}}$	$a_2^{\mathbb{P}}$	$b_{11}^{\mathbb{P}}$	$b_{21}^{\mathbb{P}}$	$b_{22}^{\mathbb{P}}$	$a_1^{\mathbb{Q}}$	$b_{11}^{\mathbb{Q}}$	$b_{21}^{\mathbb{Q}}$	$b_{22}^{\mathbb{Q}}$	δ_0	δ_1	δ_2
Est	0.0012	0.0036	1.0369	−0.4328	−0.2473	0.3499	−0.2983	2.0214	−0.2439	0.6682	−0.3560	0.0001	−0.0004	0.0059
q2.5%	0.0012	0.0001	0.5551	−1.9845	−0.6272	0.1895	−0.4363	1.8376	−0.2563	0.5898	−0.3739	0.0000	−0.0007	0.0057
q97.5%	0.0012	0.0125	3.0698	0.8063	−0.0753	0.6038	−0.1359	2.2685	−0.2295	0.7497	−0.3408	0.0005	−0.0004	0.0061

Panel B: Foreign Parameters

	AUD			CAD			CHF			EUR			GBP			JPY		
	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%
$\zeta^{\star}$	0.0015	0.0015	0.0015	0.0023	0.0023	0.0023	0.0021	0.0020	0.0099	0.0027	0.0026	0.0028	0.0029	0.0029	0.0119	0.0023	0.0023	0.0023
γ_1	0.0004	0.0000	0.0008	0.0005	0.0000	0.0018	0.0016	0.0000	0.0065	0.0009	0.0000	0.0046	0.5326	0.2105	141.9860	0.0001	0.0000	0.0016
γ_2	0.0002	0.0000	0.0005	0.2058	0.1903	0.2484	0.0880	0.0108	0.1037	0.0221	0.0166	0.0303	160.3280	43.6922	295.1040	0.0001	0.0000	0.0010
Σ_1	−0.0035	−0.0048	−0.0029	−0.0010	−0.0015	−0.0004	−0.0020	−0.0034	0.0034	−0.0037	−0.0048	−0.0023	−0.0025	−0.0062	−0.0017	0.0028	0.0017	0.0038
Σ_2	0.0095	0.0089	0.0109	0.0024	−0.0004	0.0037	−0.0057	−0.0237	−0.0026	0.0044	0.0026	0.0053	0.0024	0.0019	0.0051	−0.0054	−0.0096	0.0015
Σ_3	0.0016	0.0003	0.0036	−0.0033	−0.0043	−0.0015	0.0033	−0.0012	0.0088	0.0011	−0.0037	0.0038	0.0016	−0.0013	0.0040	−0.0226	−0.0256	−0.0197
Σ_4	−0.1030	−0.1047	−0.1023	−0.0343	−0.0356	−0.0322	−0.1029	−0.1066	−0.0998	−0.0962	−0.0984	−0.0916	−0.0006	−0.0008	−0.0005	−0.1043	−0.1060	−0.1018
$a_1^{\star\mathbb{P}}$	0.5228	0.5020	0.6651	8.9729	6.9834	10.3567	0.5415	0.5014	0.6567	0.5685	0.5041	0.8238	9.4683	1.6353	11.6699	0.5020	0.5008	0.6598
$a_2^{\star\mathbb{P}}$	17.5507	16.2030	18.1243	−70.6874	−78.2190	−56.4685	92.4746	90.6046	103.7450	3.2136	−0.3775	7.5117	−105.4120	−107.3600	−71.6949	−27.9669	−31.3595	−26.2398
$b_{11}^{\star\mathbb{P}}$	2.6327	2.3737	3.2351	0.0362	0.0012	0.1313	0.0237	0.0009	0.0857	0.0050	0.0004	0.0821	0.1139	0.0037	1.5720	0.0203	0.0005	0.0582
$b_{13}^{\star\mathbb{P}}$	−1.7699	−2.1763	−1.6307	−1.2516	−1.4324	−1.0137	−0.4459	−0.6734	−0.1530	−0.0480	−0.0893	−0.0121	−0.2583	−0.2987	−0.1534	−0.2828	−0.3178	−0.2382
$b_{21}^{\star\mathbb{P}}$	−6.1516	−7.2563	−5.5299	−0.2026	−3.0676	2.1494	89.1603	86.1016	95.8949	−11.5947	−13.1558	−10.5432	−25.9713	−31.0278	8.5852	−7.9065	−8.6165	−7.2070
$b_{22}^{\star\mathbb{P}}$	8.0640	7.1146	10.0154	13.1616	11.1984	15.2171	−101.9410	−121.7070	−86.9512	96.4639	94.9958	97.1469	180.8390	173.4650	207.0880	34.3351	33.5866	34.9210
$b_{23}^{\star\mathbb{P}}$	−0.5167	−0.6090	−0.3920	19.9765	16.9530	23.1464	45.6830	45.3458	50.8453	−27.7192	−30.4070	−23.6198	21.2037	9.8664	33.6936	−3.5655	−3.6346	−3.5376
$b_{24}^{\star\mathbb{P}}$	−6.2514	−7.0615	−5.8294	−18.1105	−21.4426	−15.1966	−109.4530	−111.5090	−108.8100	−126.3060	−130.5050	−122.7490	−191.6850	−218.0000	−186.1790	−15.5912	−15.7064	−15.3064
$a_1^{\star\mathbb{Q}}$	0.5021	0.5000	0.5071	0.5054	0.5002	0.5375	0.5005	0.5000	0.6942	0.5019	0.5000	0.5067	14.5513	1.5459	17.8573	0.5002	0.5000	0.5025
$a_2^{\star\mathbb{Q}}$	16.3712	14.9792	16.9334	−62.1151	−70.4172	−50.5235	71.6269	69.5451	74.1814	2.7006	0.2762	5.3491	37.2817	28.5245	74.6281	−25.8715	−27.9198	−24.5489
$b_{11}^{\star\mathbb{Q}}$	0.2152	0.1778	0.2324	0.3628	0.3457	0.3784	0.1201	0.1165	0.1838	0.7519	0.7259	0.7926	4.3811	3.4314	6.1378	0.1677	0.1559	0.1736
$b_{13}^{\star\mathbb{Q}}$	−0.0737	−0.0782	−0.0646	−0.2112	−0.2222	−0.2001	−0.3092	−0.3159	−0.1686	−0.2675	−0.2792	−0.2615	−0.4300	−0.4369	−0.4162	−0.0949	−0.0978	−0.0886
$b_{21}^{\star\mathbb{Q}}$	−5.7094	−6.5934	−5.1861	−0.0424	−2.7282	2.1218	69.1671	65.8495	70.4776	−7.6697	−9.0186	−6.8449	−0.3252	−7.0412	36.8939	−7.4527	−8.2085	−6.5695
$b_{22}^{\star\mathbb{Q}}$	7.3091	6.4786	8.9833	11.9562	10.4688	14.1669	−78.6974	−83.2775	−70.7910	65.1075	62.7263	66.4914	167.3930	153.0490	172.9400	31.9289	31.2603	32.3692
$b_{23}^{\star\mathbb{Q}}$	−0.7210	−0.8012	−0.6062	17.3839	14.9454	20.7767	35.1726	34.1674	37.6736	−18.9619	−21.5649	−15.5231	4.9401	−7.8595	17.2710	−3.3889	−3.4732	−3.2874
$b_{24}^{\star\mathbb{Q}}$	−5.3798	−6.0345	−5.0046	−16.1769	−19.6581	−13.8439	−84.7377	−89.3905	−76.3759	−85.1644	−85.9106	−84.1430	−178.2750	−185.7220	−162.7290	−14.4511	−14.6877	−14.0120
$\delta_0^{\star}$	0.0137	0.0128	0.0147	0.0004	0.0000	0.0008	0.0000	0.0000	0.0055	0.0110	0.0106	0.0117	0.0001	0.0000	0.0004	0.0007	0.0002	0.0014
$\delta_1^{\star}$	0.0003	0.0000	0.0006	0.0000	−0.0000	0.0001	−0.0005	−0.0034	−0.0003	0.0019	−0.0002	0.0039	−0.0016	−0.0025	−0.0014	−0.0001	−0.0002	0.0001
$\delta_2^{\star}$	−0.0001	−0.0005	0.0003	−0.0002	−0.0002	−0.0001	0.0088	0.0061	0.0114	−0.0234	−0.0343	−0.0082	0.0001	−0.0002	0.0004	−0.0010	−0.0015	−0.0005
$\delta_3^{\star}$	0.0004	0.0004	0.0005	0.0000	0.0000	0.0002	0.0011	0.0000	0.0011	0.0045	0.0010	0.0073	0.0035	0.0027	0.0037	0.0001	0.0000	0.0001
$\delta_4^{\star}$	0.0043	0.0040	0.0046	0.0040	0.0039	0.0041	0.0000	0.0000	0.0002	0.0381	0.0175	0.0531	0.0003	0.0000	0.0007	0.0028	0.0026	0.0031

Table A.2: Yield Pricing Errors and Matching Depreciation Rates: Small Model

The table reports pricing errors for domestic (US) and foreign yields as well as results for how well model implied depreciation rates match observed rates. Columns labeled "Yield Pricing Errors" report annualized root mean squared errors in basis points for the yield maturities indicated in the header. Columns labeled "Matching Depreciation Rates" report correlations of model implied and observed rates ("corr") and results of regressing the later on the former with c_0 denoting the intercept, c_1 the slope coefficient, and se($\cdot$) the respective block-bootstrapped standard errors in parentheses. R^2 is the in-sample coefficient of determination. The results are for the global model described in section *3.1* based on daily observations for the sample periods October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	11	15	16	19	37	67	95						
AUD	9	11	12	14	23	35	50	0.9996	-0.0000	(0.0000)	1.0190	(0.0005)	0.9992
CAD	24	38	47	54	54	56	71	0.9995	-0.0000	(0.0000)	0.9990	(0.0006)	0.9991
CHF	8	10	10	14	29	44	57	0.9545	-0.0000	(0.0000)	1.1431	(0.0061)	0.9111
DEM-EUR	12	18	20	21	32	49	69	0.9993	-0.0000	(0.0000)	1.0087	(0.0008)	0.9987
GBP	30	45	54	58	39	30	51	0.9979	-0.0000	(0.0000)	1.0497	(0.0013)	0.9958
JPY	7	10	12	17	23	47	79	0.9231	0.0001	(0.0000)	1.0347	(0.0106)	0.8522

Table A.3: Regressions of Excess Returns on Expected Excess Returns: Small Model

The table shows the results from estimating, by ordinary least squares, the regression (23), $ER_{t,T} = \alpha' + \beta'\widehat{ER}_{t,T} + \eta'_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are block-bootstrapped standard errors. $t[\beta' = 1]$ is the t-statistic for testing $\beta' = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α'	0.0000	0.0001	0.0007	−0.0004	−0.0065	0.0085
se(α')	(0.0001)	(0.0007)	(0.0027)	(0.0076)	(0.0235)	(0.0805)
β'	0.9249**	0.9580**	0.9491**	1.2867***	1.3708***	0.8841**
se(β')	(0.4252)	(0.4097)	(0.4436)	(0.3661)	(0.3486)	(0.3640)
$t[\beta' = 1]$	[-0.18]	[-0.10]	[-0.11]	[0.78]	[1.06]	[-0.32]
R^2	0.0024	0.0134	0.0563	0.2250	0.5117	0.4530
CAD						
α'	0.0000	0.0001	−0.0000	−0.0018	−0.0067	0.0033
se(α')	(0.0001)	(0.0003)	(0.0014)	(0.0035)	(0.0090)	(0.0353)
β'	0.1207	0.1518	0.4149	0.9399**	1.1292***	0.8966***
se(β')	(0.1341)	(0.1473)	(0.2704)	(0.3949)	(0.2356)	(0.2189)
$t[\beta' = 1]$	[-6.56]	[-5.76]	[-2.16]	[-0.15]	[0.55]	[-0.47]
R^2	0.0004	0.0026	0.0380	0.1894	0.5345	0.5961
CHF						
α'	0.0000	0.0002	0.0005	0.0016	−0.0018	−0.0086
se(α')	(0.0001)	(0.0006)	(0.0023)	(0.0067)	(0.0217)	(0.0411)
β'	0.1563*	0.3314**	0.9079***	0.9654**	1.0330**	0.8444***
se(β')	(0.0798)	(0.1596)	(0.3511)	(0.4260)	(0.4514)	(0.2721)
$t[\beta' = 1]$	[-10.57]	[-4.19]	[-0.26]	[-0.08]	[0.07]	[-0.57]
R^2	0.0008	0.0029	0.0215	0.0553	0.2115	0.3479
DEM-EUR						
α'	0.0001	0.0003	0.0010	0.0025	0.0020	0.0001
se(α')	(0.0001)	(0.0005)	(0.0020)	(0.0055)	(0.0188)	(0.0512)
β'	0.6698***	0.7241***	1.0010***	1.1782***	1.1037***	0.8412***
se(β')	(0.1683)	(0.1408)	(0.1410)	(0.1983)	(0.3661)	(0.2913)
$t[\beta' = 1]$	[-1.96]	[-1.96]	[0.01]	[0.90]	[0.28]	[-0.55]
R^2	0.0089	0.0404	0.1545	0.2044	0.3141	0.3306
GBP						
α'	0.0002	0.0009	0.0039	0.0105	0.0179	0.0126
se(α')	(0.0002)	(0.0008)	(0.0035)	(0.0107)	(0.0309)	(0.0385)
β'	−0.4337	−0.4900	−0.4784	−0.2518	0.4578	0.8147***
se(β')	(1.4099)	(1.3706)	(1.3952)	(1.3813)	(0.9305)	(0.2815)
$t[\beta' = 1]$	[-1.02]	[-1.09]	[-1.06]	[-0.91]	[-0.58]	[-0.66]
R^2	0.0001	0.0004	0.0016	0.0012	0.0190	0.3174
JPY						
α'	−0.0001	−0.0001	0.0005	0.0030	0.0129	−0.0135
se(α')	(0.0002)	(0.0006)	(0.0022)	(0.0058)	(0.0204)	(0.0472)
β'	0.6026***	0.9029***	0.5413*	0.8397***	0.9897***	0.8495***
se(β')	(0.1038)	(0.2269)	(0.3028)	(0.3204)	(0.2887)	(0.2008)
$t[\beta' = 1]$	[-3.83]	[-0.43]	[-1.51]	[-0.50]	[-0.04]	[-0.75]
R^2	0.0319	0.0549	0.0165	0.0723	0.3426	0.5853

Table A.4: Ability to Predict Excess Returns: Small Model

The table reports results related to the predictive ability of the model as compared to the UIP and RW benchmarks. Hit-ratios (HR) are calculated as the proportion of times the sign of the excess return is correctly predicted by the model. $R2 = 1 - MSE_M/MSE_B$ where MSE_M denotes the mean squared prediction error of the model and MSE_B that of the benchmark. CW and GW denote the test-statistics of Clark and West (2007) and Giacomini and White (2006) as described in Section *3.3*. The one-sided p-values of the test-statistics in square brackets are obtained from the block bootstrap procedure described in Appendix F which accounts for autocorrelation and heteroscedasticity. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to October 10, 2008 for AUD; June 1, 1993 to October 10, 2008 for CAD; and September 18, 1989 to October 10, 2008 for CHF, DEM-EUR, GBP, and JPY.

	Model vs. UIP						Model vs. RW					
	1d	1w	1m	3m	1y	4y	1d	1w	1m	3m	1y	4y
AUD												
HR	0.5213	0.5655	0.6250	0.7000	0.8000	0.8000	0.5213	0.5655	0.6250	0.7000	0.8000	0.8000
$R2$	0.0025	0.0141	0.0596	0.2292	0.5172	0.4929	0.0012	0.0072	0.0278	0.1607	0.4115	0.4271
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.153]	[0.127]	[0.068]	[<0.01]	[<0.01]	[<0.01]	[0.225]	[0.181]	[0.141]	[0.018]	[0.018]	[<0.01]
CAD												
HR	0.5176	0.5702	0.6324	0.5882	0.7426	0.6544	0.5176	0.5702	0.6324	0.5882	0.7426	0.6544
$R2$	0.0005	0.0028	0.0386	0.1908	0.5433	0.6642	-0.0008	-0.0032	0.0155	0.1349	0.4339	0.6298
p-value[CW]	[0.106]	[0.097]	[0.021]	[<0.01]	[<0.01]	[<0.01]	[0.169]	[0.166]	[0.050]	[0.021]	[<0.01]	[<0.01]
p-value[GW]	[0.414]	[0.115]	[0.260]	[0.141]	[0.030]	[<0.01]	[0.326]	[0.105]	[0.353]	[0.176]	[0.080]	[<0.01]
CHF												
HR	0.5303	0.5272	0.5889	0.6833	0.7667	0.7611	0.5303	0.5272	0.5889	0.6833	0.7667	0.7611
$R2$	0.0008	0.0031	0.0225	0.0573	0.2115	0.3573	0.0002	0.0000	0.0091	0.0245	0.1123	0.2530
p-value[CW]	[0.056]	[0.069]	[0.031]	[0.019]	[<0.01]	[<0.01]	[0.081]	[0.172]	[0.148]	[0.104]	[<0.01]	[<0.01]
p-value[GW]	[0.376]	[0.209]	[0.173]	[0.053]	[0.027]	[<0.01]	[0.553]	[0.243]	[0.345]	[0.084]	[0.063]	[<0.01]
DEM-EUR												
HR	0.5422	0.5954	0.6389	0.6611	0.7389	0.7778	0.5422	0.5954	0.6389	0.6611	0.7389	0.7778
$R2$	0.0090	0.0410	0.1572	0.2096	0.3178	0.3336	0.0085	0.0383	0.1454	0.1772	0.2049	0.2452
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.011]	[<0.01]	[<0.01]	[0.020]	[<0.01]
GBP												
HR	0.5248	0.5082	0.5056	0.5000	0.5556	0.6778	0.5248	0.5082	0.5056	0.5000	0.5556	0.6778
$R2$	0.0007	0.0029	0.0128	0.0327	0.1092	0.5268	0.0000	0.0001	-0.0001	-0.0029	0.0077	0.4963
p-value[CW]	[0.237]	[0.262]	[0.290]	[0.144]	[0.028]	[<0.01]	[0.297]	[0.306]	[0.359]	[0.245]	[0.012]	[<0.01]
p-value[GW]	[<0.01]	[0.384]	[0.424]	[0.247]	[0.101]	[<0.01]	[<0.01]	[0.437]	[0.469]	[0.301]	[0.104]	[<0.01]
JPY												
HR	0.5455	0.5702	0.5833	0.6167	0.7222	0.9444	0.5455	0.5702	0.5833	0.6167	0.7222	0.9444
$R2$	0.0319	0.0550	0.0167	0.0728	0.3459	0.6522	0.0311	0.0517	-0.0004	0.0305	0.2006	0.4532
p-value[CW]	[<0.01]	[<0.01]	[0.040]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.243]	[0.019]	[<0.01]	[0.032]
p-value[GW]	[<0.01]	[<0.01]	[0.281]	[0.084]	[0.014]	[<0.01]	[<0.01]	[0.010]	[0.254]	[0.161]	[0.021]	[0.018]

Table A.5: Yield Pricing Errors, Matching Depreciation Rates, and Fitting Model-Free Implied Variance: Sample 01/1996 to 10/2008

The table reports pricing errors for domestic (US) and foreign yields as well as results for how well model implied depreciation rates match observed rates. Columns labeled "Yield Pricing Errors" report annualized root mean squared errors in basis points for the yield maturities indicated in the header. Columns labeled "Matching Depreciation Rates" report correlations of model implied and observed rates ("corr") and results of regressing the later on the former with c_0 denoting the intercept, c_1 the slope coefficient, and se($\cdot$) the respective block-bootstrapped standard errors in parentheses. R^2 is the in-sample coefficient of determination. Panel A presents results for the global model described in section *3.1* and Panel B presents results for the model that accounts for information in currency options as described in Section *5.2*. Panel C presents descriptives for model-free implied variance (MFIV) estimates and MFIV pricing errors when the estimation conditions on MFIV. The results are based on daily observations for the sample periods are January 24, 1996 to October 10, 2008 for AUD, CAD, CHF, GBP, and JPY. For DEM-EUR the sample period is January 1, 1998 to October 10, 2008.

Panel A: Global Model

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	4	3	6	14	13	11	21						
AUD	5	6	8	12	15	23	37	0.9957	0.0000	(0.0000)	1.0261	(0.0020)	0.9914
CAD	5	6	7	15	23	35	53	0.9986	0.0000	(0.0000)	1.0227	(0.0012)	0.9972
CHF	6	6	7	12	20	30	41	0.9004	0.0000	(0.0000)	0.9445	(0.0109)	0.8107
DEM-EUR	6	7	6	10	19	27	35	0.9086	0.0000	(0.0001)	1.0158	(0.0112)	0.8255
GBP	7	7	8	17	23	40	63	0.9774	-0.0000	(0.0000)	1.1021	(0.0049)	0.9552
JPY	5	7	9	9	16	33	52	0.9990	0.0000	(0.0000)	1.0538	(0.0013)	0.9979

Panel B: Global Model including Information in Currency Options

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	4	3	6	14	13	11	21						
AUD	4	6	8	11	14	23	37	0.9963	-0.0000	(0.0000)	1.0244	(0.0020)	0.9926
CAD	5	6	7	14	22	34	53	0.9989	-0.0000	(0.0000)	1.0259	(0.0011)	0.9978
CHF	6	6	6	12	20	30	41	0.8878	0.0000	(0.0000)	0.9418	(0.0115)	0.7882
DEM-EUR	6	7	6	10	19	27	35	0.8869	0.0000	(0.0001)	0.9990	(0.0131)	0.7866
GBP	7	7	8	17	22	40	62	0.9742	-0.0000	(0.0000)	1.1185	(0.0057)	0.9491
JPY	4	7	8	8	15	30	47	0.9989	0.0000	(0.0000)	1.0566	(0.0015)	0.9977

Panel C: Descriptive Statistics for MFIV and Pricing Errors

	1-Month Options				3-Month Options			
	MFIV		Pricing Errors		MFIV		Pricing Errors	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
AUD	0.1111	0.0266	0.0003	0.0269	0.1076	0.0230	0.0038	0.0233
CAD	0.0671	0.0190	−0.0050	0.0166	0.0657	0.0166	−0.0029	0.0141
CHF	0.1119	0.0154	−0.0025	0.0157	0.1143	0.0125	−0.0051	0.0130
DEM-EUR	0.1110	0.0182	−0.0041	0.0170	0.1124	0.0152	−0.0054	0.0138
GBP	0.0861	0.0147	0.0002	0.0159	0.0885	0.0120	−0.0025	0.0132
JPY	0.1202	0.0331	0.0051	0.0345	0.1210	0.0282	0.0046	0.0289

Table A.6: Regressions of Excess Returns on Expected Excess Returns: Sample 01/1996 to 10/2008

The table shows the results from estimating, by ordinary least squares, the regression (23), $ER_{t,T} = \alpha' + \beta'\widehat{ER}_{t,T} + \eta'_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are block-bootstrapped standard errors. $t[\beta' = 1]$ is the t-statistic for testing $\beta' = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are January 24, 1996 to October 10, 2008 for AUD, CAD, CHF, GBP, and JPY. For DEM-EUR the sample period is January 1, 1998 to October 10, 2008.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α'	0.0001	0.0003	0.0018	0.0055	0.0028	0.0234
se(α')	(0.0002)	(0.0007)	(0.0027)	(0.0068)	(0.0257)	(0.0898)
β'	0.6311**	0.7629**	1.0990***	1.3020***	1.2971***	0.8069**
se(β')	(0.3117)	(0.3242)	(0.3134)	(0.3495)	(0.3506)	(0.3144)
$t[\beta' = 1]$	[-1.18]	[-0.73]	[0.32]	[0.86]	[0.85]	[-0.61]
R^2	0.0017	0.0125	0.0918	0.3046	0.6172	0.3686
CAD						
α'	0.0000	0.0002	0.0004	0.0000	−0.0068	0.0031
se(α')	(0.0001)	(0.0004)	(0.0013)	(0.0033)	(0.0076)	(0.0339)
β'	0.0735	0.2137	0.6613***	0.8933***	1.0452***	0.9984***
se(β')	(0.1679)	(0.2041)	(0.2372)	(0.2291)	(0.1522)	(0.1340)
$t[\beta' = 1]$	[-5.52]	[-3.85]	[-1.43]	[-0.47]	[0.30]	[-0.01]
R^2	0.0001	0.0024	0.0660	0.2373	0.7342	0.7647
CHF						
α'	−0.0000	−0.0001	0.0005	0.0026	0.0019	−0.0033
se(α')	(0.0001)	(0.0006)	(0.0027)	(0.0077)	(0.0186)	(0.0439)
β'	0.5902***	0.6574***	0.8048***	1.0554***	1.1648***	0.9620***
se(β')	(0.1318)	(0.1579)	(0.2232)	(0.2842)	(0.2482)	(0.1985)
$t[\beta' = 1]$	[-3.11]	[-2.17]	[-0.87]	[0.19]	[0.66]	[-0.19]
R^2	0.0249	0.0405	0.0501	0.1580	0.5423	0.5199
DEM-EUR						
α'	−0.0001	−0.0000	0.0017	0.0047	−0.0061	0.0239
se(α')	(0.0002)	(0.0007)	(0.0037)	(0.0080)	(0.0122)	(0.0625)
β'	1.0570***	0.7741***	0.6238*	1.1669***	1.5131***	0.8066***
se(β')	(0.1254)	(0.1358)	(0.3356)	(0.3423)	(0.1386)	(0.2130)
$t[\beta' = 1]$	[0.45]	[-1.66]	[-1.12]	[0.49]	[3.70]	[-0.91]
R^2	0.1264	0.0845	0.0413	0.2111	0.8016	0.6240
GBP						
α'	0.0002**	0.0007	0.0009	0.0010	−0.0005	−0.0032
se(α')	(0.0001)	(0.0005)	(0.0023)	(0.0070)	(0.0223)	(0.0335)
β'	−0.1942	0.0779	1.1666**	1.3306***	1.2225***	0.9788***
se(β')	(0.1390)	(0.2763)	(0.5132)	(0.4962)	(0.4373)	(0.1442)
$t[\beta' = 1]$	[-8.59]	[-3.34]	[0.32]	[0.67]	[0.51]	[-0.15]
R^2	0.0003	0.0001	0.0397	0.1601	0.4197	0.6419
JPY						
α'	0.0002	0.0001	0.0001	0.0052	0.0345	−0.0296
se(α')	(0.0003)	(0.0009)	(0.0038)	(0.0090)	(0.0225)	(0.0469)
β'	1.3048**	0.6544	0.6008	1.0009**	1.5739***	0.7871**
se(β')	(0.6125)	(0.3995)	(0.5140)	(0.4788)	(0.4942)	(0.3184)
$t[\beta' = 1]$	[0.50]	[-0.86]	[-0.78]	[0.00]	[1.16]	[-0.67]
R^2	0.0032	0.0041	0.0118	0.0640	0.3102	0.2805

Table A.7: Regressions of Excess Returns on Expected Excess Returns: Sample 01/1996 to 10/2008 including Currency Options

The table shows the results from estimating, by ordinary least squares, the regression (23), $ER_{t,T} = \alpha' + \beta' \widehat{ER}_{t,T} + \eta'_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are block-bootstrapped standard errors. $t[\beta' = 1]$ is the t-statistic for testing $\beta' = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are January 24, 1996 to October 10, 2008 for AUD, CAD, CHF, GBP, and JPY. For DEM-EUR the sample period is January 1, 1998 to October 10, 2008.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α'	0.0000	0.0003	0.0016	0.0057	0.0054	0.0175
se(α')	(0.0001)	(0.0007)	(0.0028)	(0.0067)	(0.0249)	(0.0911)
β'	0.7983**	0.8625**	1.1095***	1.3339***	1.3164***	0.7856**
se(β')	(0.3261)	(0.3384)	(0.3303)	(0.3412)	(0.3430)	(0.3095)
$t[\beta' = 1]$	[-0.62]	[-0.41]	[0.33]	[0.98]	[0.92]	[-0.69]
R^2	0.0023	0.0139	0.0864	0.3009	0.6361	0.3719
CAD						
α'	0.0000	0.0002	0.0007	0.0012	−0.0031	−0.0008
se(α')	(0.0001)	(0.0004)	(0.0014)	(0.0035)	(0.0078)	(0.0334)
β'	0.2620	0.2853	0.5862**	0.8365***	1.0189***	0.9981***
se(β')	(0.1863)	(0.2058)	(0.2324)	(0.2259)	(0.1509)	(0.1285)
$t[\beta' = 1]$	[-3.96]	[-3.47]	[-1.78]	[-0.72]	[0.12]	[-0.01]
R^2	0.0007	0.0045	0.0592	0.2285	0.7328	0.7664
CHF						
α'	−0.0000	−0.0000	0.0006	0.0024	0.0013	−0.0038
se(α')	(0.0001)	(0.0007)	(0.0026)	(0.0079)	(0.0183)	(0.0441)
β'	0.6983***	0.6569***	0.7093***	0.9655***	1.1230***	0.9748***
se(β')	(0.1032)	(0.1422)	(0.1949)	(0.2873)	(0.2408)	(0.2006)
$t[\beta' = 1]$	[-2.92]	[-2.41]	[-1.49]	[-0.12]	[0.51]	[-0.13]
R^2	0.0451	0.0453	0.0466	0.1523	0.5473	0.5216
DEM-EUR						
α'	−0.0001	−0.0003	0.0019	0.0051	−0.0056	0.0369
se(α')	(0.0003)	(0.0007)	(0.0027)	(0.0078)	(0.0127)	(0.0584)
β'	1.0159***	0.8894***	0.7747**	1.0622***	1.4242***	0.7559***
se(β')	(0.1083)	(0.1355)	(0.3836)	(0.2983)	(0.1280)	(0.1940)
$t[\beta' = 1]$	[0.15]	[-0.82]	[-0.59]	[0.21]	[3.31]	[-1.26]
R^2	0.2020	0.1786	0.0693	0.1897	0.7949	0.6284
GBP						
α'	0.0001	0.0005	0.0009	0.0011	0.0003	0.0010
se(α')	(0.0001)	(0.0004)	(0.0024)	(0.0079)	(0.0250)	(0.0299)
β'	0.3529***	0.4692**	1.0896**	1.2216**	1.1351**	0.9260***
se(β')	(0.1121)	(0.2281)	(0.4739)	(0.5412)	(0.4765)	(0.1237)
$t[\beta' = 1]$	[-5.77]	[-2.33]	[0.19]	[0.41]	[0.28]	[-0.60]
R^2	0.0022	0.0034	0.0355	0.1350	0.3712	0.6548
JPY						
α'	0.0001	−0.0001	−0.0009	0.0001	0.0168	−0.0357
se(α')	(0.0002)	(0.0008)	(0.0038)	(0.0083)	(0.0244)	(0.0453)
β'	1.1021**	0.6532*	0.4919	0.8068**	1.4156***	0.7554**
se(β')	(0.5526)	(0.3433)	(0.4290)	(0.3551)	(0.4000)	(0.3029)
$t[\beta' = 1]$	[0.18]	[-1.01]	[-1.18]	[-0.54]	[1.04]	[-0.81]
R^2	0.0037	0.0068	0.0138	0.0669	0.3619	0.2948

Table A.8: Ability to Predict Excess Returns: Sample 01/1996 to 10/2008

The table reports results related to the predictive ability of the model as compared to the UIP and RW benchmarks. Hit-ratios (HR) are calculated as the proportion of times the sign of the excess return is correctly predicted by the model. $R2 = 1 - MSE_M/MSE_B$ where MSE_M denotes the mean squared prediction error of the model and MSE_B that of the benchmark. CW and GW denote the test-statistics of Clark and West (2007) and Giacomini and White (2006) as described in Section *3.3*. The one-sided p-values of the test-statistics in square brackets are obtained from the block bootstrap procedure described in Appendix F which accounts for autocorrelation and heteroscedasticity. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are January 24, 1996 to October 10, 2008 for AUD, CAD, CHF, GBP, and JPY. For DEM-EUR the sample period is January 1, 1998 to October 10, 2008.

	Model vs. UIP						Model vs. RW					
	1d	1w	1m	3m	1y	4y	1d	1w	1m	3m	1y	4y
AUD												
HR	0.5403	0.5739	0.6286	0.7524	0.8381	0.7143	0.5403	0.5739	0.6286	0.7524	0.8381	0.7143
$R2$	0.0018	0.0132	0.0943	0.3082	0.6183	0.4339	0.0005	0.0057	0.0648	0.2459	0.5375	0.3385
p-value[CW]	[0.017]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.056]	[0.024]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.289]	[0.132]	[0.050]	[0.012]	[<0.01]	[<0.01]	[0.449]	[0.183]	[0.090]	[0.023]	[<0.01]	[<0.01]
CAD												
HR	0.5272	0.5652	0.6476	0.6476	0.8857	0.7238	0.5272	0.5652	0.6476	0.6476	0.8857	0.7238
$R2$	0.0003	0.0034	0.0709	0.2451	0.7403	0.8266	-0.0011	-0.0037	0.0421	0.1806	0.6703	0.8042
p-value[CW]	[0.285]	[0.100]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.505]	[0.276]	[0.020]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.351]	[0.170]	[0.205]	[0.056]	[<0.01]	[<0.01]	[0.269]	[0.240]	[0.312]	[0.106]	[<0.01]	[<0.01]
CHF												
HR	0.5590	0.5761	0.5714	0.6857	0.8667	0.8762	0.5590	0.5761	0.5714	0.6857	0.8667	0.8762
$R2$	0.0251	0.0415	0.0536	0.1671	0.5638	0.5278	0.0240	0.0355	0.0283	0.1057	0.4440	0.4907
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.011]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[0.045]	[0.173]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.070]	[0.267]	[0.012]	[<0.01]	[<0.01]
DEM-EUR												
HR	0.6175	0.5850	0.6220	0.6220	0.9146	0.9268	0.6175	0.5850	0.6220	0.6220	0.9146	0.9268
$R2$	0.1265	0.0852	0.0458	0.2216	0.8036	0.7417	0.1256	0.0806	0.0237	0.1714	0.7591	0.7534
p-value[CW]	[<0.01]	[<0.01]	[0.011]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.042]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[<0.01]	[0.265]	[<0.01]	[<0.01]	[1.000]	[<0.01]	[<0.01]	[0.384]	[0.016]	[<0.01]	[1.000]
GBP												
HR	0.5120	0.5283	0.5524	0.6000	0.6095	0.8476	0.5120	0.5283	0.5524	0.6000	0.6095	0.8476
$R2$	0.0012	0.0050	0.0658	0.2246	0.5154	0.7607	0.0001	-0.0011	0.0351	0.1386	0.3553	0.7128
p-value[CW]	[0.732]	[0.272]	[0.014]	[<0.01]	[<0.01]	[<0.01]	[0.841]	[0.554]	[0.043]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.364]	[0.073]	[0.290]	[0.065]	[0.029]	[<0.01]	[0.537]	[0.217]	[0.417]	[0.086]	[0.054]	[<0.01]
JPY												
HR	0.5381	0.5652	0.4952	0.5905	0.6667	1.0000	0.5381	0.5652	0.4952	0.5905	0.6667	1.0000
$R2$	0.0036	0.0062	0.0203	0.0868	0.3867	0.8603	0.0028	0.0016	-0.0011	0.0276	0.1841	0.1370
p-value[CW]	[<0.01]	[0.061]	[0.105]	[0.030]	[0.013]	[<0.01]	[0.011]	[0.241]	[0.418]	[0.166]	[0.047]	[<0.01]
p-value[GW]	[0.204]	[0.395]	[0.381]	[0.163]	[0.056]	[<0.01]	[0.216]	[0.580]	[0.427]	[0.185]	[0.031]	[<0.01]

Table A.9: Ability to Predict Excess Returns: Sample 01/1996 to 10/2008 including Currency Options

The table reports results related to the predictive ability of the model as compared to the UIP and RW benchmarks. Hit-ratios (HR) are calculated as the proportion of times the sign of the excess return is correctly predicted by the model. $R2 = 1 - MSE_M/MSE_B$ where MSE_M denotes the mean squared prediction error of the model and MSE_B that of the benchmark. CW and GW denote the test-statistics of Clark and West (2007) and Giacomini and White (2006) as described in Section *3.3*. The one-sided p-values of the test-statistics in square brackets are obtained from the block bootstrap procedure described in Appendix F which accounts for autocorrelation and heteroscedasticity. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are January 24, 1996 to October 10, 2008 for AUD, CAD, CHF, GBP, and JPY. For DEM-EUR the sample period is January 1, 1998 to October 10, 2008.

	Model vs. UIP						Model vs. RW					
	1d	1w	1m	3m	1y	4y	1d	1w	1m	3m	1y	4y
AUD												
HR	0.5329	0.5761	0.6190	0.7333	0.8571	0.7429	0.5329	0.5761	0.6190	0.7333	0.8571	0.7429
$R2$	0.0024	0.0146	0.0889	0.3045	0.6371	0.4368	0.0010	0.0072	0.0592	0.2419	0.5604	0.3419
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.031]	[0.012]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.269]	[0.160]	[0.065]	[0.013]	[<0.01]	[<0.01]	[0.385]	[0.241]	[0.120]	[0.024]	[<0.01]	[<0.01]
CAD												
HR	0.5233	0.5543	0.6571	0.6476	0.8762	0.7429	0.5233	0.5543	0.6571	0.6476	0.8762	0.7429
$R2$	0.0009	0.0055	0.0642	0.2363	0.7390	0.8278	-0.0004	-0.0016	0.0351	0.1711	0.6687	0.8055
p-value[CW]	[0.064]	[0.038]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.168]	[0.132]	[0.018]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.248]	[0.226]	[0.200]	[0.064]	[<0.01]	[<0.01]	[0.366]	[0.367]	[0.303]	[0.122]	[<0.01]	[<0.01]
CHF												
HR	0.5847	0.5696	0.5810	0.6952	0.8667	0.8762	0.5847	0.5696	0.5810	0.6952	0.8667	0.8762
$R2$	0.0453	0.0463	0.0500	0.1614	0.5686	0.5295	0.0442	0.0403	0.0246	0.0996	0.4500	0.4925
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.018]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[0.043]	[0.173]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.065]	[0.257]	[0.013]	[<0.01]	[<0.01]
DEM-EUR												
HR	0.6488	0.6574	0.6463	0.6341	0.8902	0.9146	0.6488	0.6574	0.6463	0.6341	0.8902	0.9146
$R2$	0.2022	0.1793	0.0737	0.2005	0.7969	0.7448	0.2014	0.1751	0.0523	0.1489	0.7509	0.7563
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[<0.01]	[<0.01]	[0.092]	[0.011]	[<0.01]	[1.000]	[<0.01]	[<0.01]	[0.132]	[0.021]	[<0.01]	[1.000]
GBP												
HR	0.5294	0.5261	0.5619	0.5810	0.6190	0.8571	0.5294	0.5261	0.5619	0.5810	0.6190	0.8571
$R2$	0.0031	0.0083	0.0617	0.2014	0.4749	0.7693	0.0020	0.0022	0.0308	0.1128	0.3014	0.7231
p-value[CW]	[0.018]	[0.046]	[0.018]	[<0.01]	[<0.01]	[<0.01]	[0.028]	[0.128]	[0.061]	[<0.01]	[<0.01]	[<0.01]
p-value[GW]	[0.224]	[0.052]	[0.304]	[0.080]	[0.039]	[<0.01]	[0.372]	[0.210]	[0.440]	[0.096]	[0.072]	[<0.01]
JPY												
HR	0.5442	0.5848	0.5238	0.6476	0.6476	1.0000	0.5442	0.5848	0.5238	0.6476	0.6476	1.0000
$R2$	0.0041	0.0089	0.0222	0.0896	0.4327	0.8631	0.0033	0.0043	0.0008	0.0306	0.2453	0.1542
p-value[CW]	[<0.01]	[0.018]	[0.064]	[0.016]	[<0.01]	[<0.01]	[<0.01]	[0.071]	[0.234]	[0.078]	[<0.01]	[<0.01]
p-value[GW]	[0.153]	[0.357]	[0.351]	[0.152]	[0.044]	[<0.01]	[0.143]	[0.456]	[0.405]	[0.177]	[0.012]	[<0.01]

Table A.10: Model Parameters: Sample 01/1996 to 10/2008

The table shows parameter estimates for our data set. The values reported are based on the third factor rotation described in Section *4.3.2* and in Appendix C. Point estimates are based on the draw from the posterior distribution with minimal L1 distance to the other draws. Confidence intervals are computed from the empirical posterior distribution.

	AUD			CAD			CHF			EUR			GBP			JPY		
	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%
φ_1	-0.0000	-0.0000	-0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	-0.0915	-0.1017	-0.0812	-0.0000	-0.0001	0.0001	-0.0001	-0.0001	-0.0001
φ_2	0.0016	0.0007	0.0075	0.0196	0.0106	0.0303	0.0756	0.0027	0.1001	-27.440	-33.405	-22.341	-0.3831	-1.8470	3.5437	0.0011	0.0011	0.0014
φ_3	0.0001	-0.0014	0.0009	-0.0019	-0.0095	-0.0003	0.0003	-0.0014	0.0009	-0.0363	-0.0412	-0.0327	0.0034	0.0021	0.0054	-0.0133	-0.0143	-0.0117
φ_4	-0.0928	-0.1114	-0.0188	0.3531	0.1603	0.9052	-0.0196	-0.1226	0.5383	-63.782	-75.964	-55.481	-1.7233	-2.0970	-1.4647	1.3033	1.1037	1.4594
ϑ_{11}	-0.1360	-0.1487	-0.1212	-3.4170	-4.2204	-3.1517	-0.3776	-0.3928	-0.3586	-2.0212	-2.2149	-1.7914	-0.8802	-10.1498	-0.4140	-0.1057	-0.1137	-0.0929
ϑ_{12}	0.0060	0.0024	0.0102	0.0164	0.0079	0.0330	0.0000	0.0000	0.0004	0.0051	0.0046	0.0054	0.0000	0.0000	0.0003	0.0147	0.0133	0.0154
ϑ_{21}	0.0066	0.0008	0.0190	-518.71	-1019.2	-389.22	-153.12	-261.01	-1.8992	-617.58	-737.91	-507.86	-12568	-307864	-547.59	0.4581	0.3883	0.5261
ϑ_{22}	-0.2436	-0.2438	-0.2421	2.6226	2.3707	3.4078	-0.2300	-0.2403	-0.2221	1.5381	1.3054	1.7375	0.3073	-0.1554	9.5854	-0.1949	-0.2076	-0.1849
ϑ_{31}	-89.927	-126.61	-46.438	-242.07	-514.76	-162.52	-211.37	-281.94	-65.337	-5.1378	-5.3667	-4.8648	-412.66	-524.46	-350.01	-174.62	-178.14	-168.65
ϑ_{32}	0.2951	0.0995	0.4884	0.6865	0.1589	3.3939	0.0139	0.0119	0.1516	0.0025	0.0023	0.0026	0.0158	0.0129	0.0224	2.2997	2.1301	2.4448
ϑ_{33}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ϑ_{34}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ϑ_{41}	1172.6	981.85	1320.0	11168	7244.9	29176	16661	6125.8	21692	-458.33	-656.18	-265.17	70310	55885	102222	4255.5	4149.4	4680.7
ϑ_{42}	-16.420	-19.217	-9.3877	-55.188	-247.50	-13.873	0.7952	-46.194	1.0499	3.1696	2.7359	3.6050	-2.7940	-4.1521	-2.2818	-231.50	-240.56	-213.48
ϑ_{43}	-13.492	-19.991	-11.172	-23.072	-33.377	-18.337	-122.01	-124.78	-117.45	-107.75	-112.37	-103.50	-221.49	-245.21	-193.63	-21.038	-23.611	-20.255
ϑ_{44}	-10.306	-15.099	-8.5949	-17.371	-24.970	-13.879	-90.335	-92.374	-86.972	-79.820	-83.222	-76.683	-163.69	-181.19	-143.15	-15.871	-17.768	-15.293
c_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0000	0.0000	0.0000
c_2	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0014	0.0013	0.0014	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000
d_1	0.0026	0.0013	0.0104	0.0007	0.0002	0.0030	0.1040	0.0033	0.1352	0.2298	0.2104	0.2600	3.5071	0.2535	10.3469	0.0002	0.0002	0.0002
d_2	0.0000	0.0000	0.0000	0.0077	0.0047	0.0184	0.0338	0.0015	0.0432	0.4790	0.4403	0.5204	1.0615	0.0429	6.2231	0.0001	0.0001	0.0001
κ_1	-0.0019	-0.0036	-0.0012	-0.0005	-0.0006	-0.0005	0.0020	-0.0010	0.0025	-0.0049	-0.0054	-0.0044	0.0003	0.0001	0.0004	-0.0002	-0.0003	-0.0002
κ_2	0.0081	0.0068	0.0112	0.0059	0.0059	0.0060	0.0055	0.0048	0.0096	0.0371	0.0361	0.0380	0.0038	0.0035	0.0042	0.0059	0.0059	0.0060
κ_3	-0.0005	-0.0005	-0.0004	-0.0000	-0.0001	-0.0000	-0.0011	-0.0027	-0.0008	-0.0093	-0.0097	-0.0085	-0.0029	-0.0034	-0.0025	-0.0000	-0.0000	-0.0000
κ_4	-0.0058	-0.0081	-0.0050	-0.0040	-0.0041	-0.0039	-0.0049	-0.0056	-0.0009	-0.0437	-0.0444	-0.0427	-0.0008	-0.0013	-0.0002	-0.0020	-0.0021	-0.0019
ρ_1	0.0504	0.0354	0.1016	0.0269	0.0132	0.0545	-0.3191	-0.3650	-0.0565	0.4436	0.4245	0.4613	-0.0080	-0.0149	-0.0019	0.0133	0.0129	0.0138
ρ_2	0.0013	-0.0035	0.0028	-0.0681	-0.0873	-0.0576	-0.1788	-0.2033	-0.0378	0.6880	0.6601	0.7162	-0.0670	-0.1109	-0.0153	0.0107	0.0091	0.0113
ρ_3	-0.0800	-0.1716	-0.0514	-0.0605	-0.0896	-0.0479	0.4207	0.0789	0.4817	-2.6076	-2.6999	-2.5218	-0.0856	-0.1546	-0.0161	-0.0702	-0.0742	-0.0683
ρ_4	0.0577	0.0410	0.1191	0.0680	0.0526	0.1004	0.4440	0.0772	0.5094	3.4488	3.2951	3.6080	0.1226	0.0274	0.2151	0.0305	0.0284	0.0362
f_0	-3.8040	-4.4320	-3.3705	-7.9527	-23.542	-4.2468	-3.4914	-3.6787	-3.3650	-81.137	-94.305	-71.455	0.1327	0.0684	0.6205	-30.935	-33.232	-27.272
f_1	-16.721	-131.83	-1.7639	-238575	-767824	-116164	-11491	-14854	-4875.2	-1580.3	-1769.8	-1319.1	-16654	-91935	-8327.7	-17663	-19865	-12301
f_2	389.86	95.833	791.38	1445.4	340.96	6926.6	10.085	8.0866	304.93	4.5251	4.0103	4.9123	1.0327	0.5095	4.7005	5143.7	4755.3	5477.5
g_0	-0.3141	-0.4341	-0.0866	-0.2876	-0.3024	-0.1526	-0.3233	-0.4344	-0.0471	0.1090	-0.0358	0.2460	-0.5802	-0.9216	-0.3618	-0.0609	-0.0685	-0.0516
g_1	15356	7929.6	21612	23154	19043	30637	35255	10792	47051	756.41	722.29	790.57	68755	59134	83896	28530	27633	29045
g_2	-21.232	-26.275	-9.8345	-9.3167	-61.729	-1.5389	-1.5372	-3.0880	-0.1048	-0.0860	-0.0989	-0.0745	-2.6123	-3.5918	-2.1150	-8.4049	-10.146	-6.4093
y_0	0.9864	0.9841	0.9879	0.9715	0.9156	0.9848	0.9875	0.9868	0.9879	0.7090	0.6618	0.7437	1.0005	1.0002	1.0022	0.8891	0.8808	0.9022
y_1	-0.0600	-0.4728	-0.0063	-855.66	-2753.8	-416.62	-41.214	-53.273	-17.485	-5.6678	-6.3474	-4.7310	-59.733	-329.73	-29.868	-63.351	-71.247	-44.118
y_2	1.3982	0.3437	2.8383	5.1841	1.2229	24.843	0.0362	0.0290	1.0936	0.0162	0.0144	0.0176	0.0037	0.0018	0.0169	18.448	17.055	19.645
z_0	0.9993	0.9968	1.0000	0.7943	0.6819	0.9170	0.9626	0.8879	0.9955	0.9550	0.7704	0.9986	-0.2832	-0.4870	-0.0348	0.9874	0.9261	0.9989
z_1	2.5060	0.1472	14.774	15209	12372	20262	142.69	-162.25	705.31	-0.4993	-4.0596	0.6011	-21685	-26947	-13289	24.441	-19.010	1280.7
z_2	0.0442	-0.0039	0.4939	-4.3299	-24.733	0.3427	0.0942	-0.0164	6.0592	0.0025	0.0001	0.0121	67.344	22.160	1332.5	2.0262	0.1150	11.457

Table A.11: Model Parameters: Sample 01/1996 to 10/2008 including Currency Options

The table shows parameter estimates for our data set. The values reported are based on the third factor rotation described in Section *4.3.2* and in Appendix C. Point estimates are based on the draw from the posterior distribution with minimal L1 distance to the other draws. Confidence intervals are computed from the empirical posterior distribution.

	AUD			CAD			CHF			EUR			GBP			JPY		
	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%	Est	q2.5%	q97.5%
φ_1	-0.0000	-0.0001	-0.0000	0.0002	0.0001	0.0004	0.0000	0.0000	0.0000	-0.0764	-0.0859	-0.0686	0.0000	0.0000	0.0002	-0.0001	-0.0001	-0.0000
φ_2	0.0014	0.0006	0.0070	0.0295	0.0262	0.0357	0.0702	0.0179	0.0967	-31.515	-37.480	-27.997	0.0959	-0.0012	3.9112	0.0007	0.0005	0.0009
φ_3	0.0004	-0.0013	0.0013	0.0011	0.0004	0.0011	0.0014	-0.0007	0.0031	-0.0275	-0.0308	-0.0225	0.0018	0.0015	0.0027	-0.0095	-0.0116	-0.0068
φ_4	-0.1071	-0.1211	-0.0285	0.1446	0.0875	0.2876	-0.1577	-0.3374	0.2850	-103.67	-117.09	-90.601	-0.6731	-1.2548	0.7862	0.7127	0.4148	1.0067
ϑ_{11}	-0.1374	-0.1495	-0.1232	-2.7409	-3.4175	-2.3056	-0.4045	-0.4406	-0.3663	-2.3488	-2.6346	-2.1591	-1.4510	-18.683	-0.7035	-0.1184	-0.1241	-0.1090
ϑ_{12}	0.0075	0.0029	0.0125	0.0159	0.0081	0.0335	0.0000	0.0000	0.0001	0.0045	0.0042	0.0050	0.0003	0.0001	0.1080	0.0183	0.0163	0.0196
ϑ_{21}	0.0046	0.0006	0.0117	-282.87	-764.24	-240.73	-254.80	-580.55	-17.430	-985.23	-1161.1	-866.66	-5287.3	-398668	-2.5146	0.4514	0.4254	0.4752
ϑ_{22}	-0.2437	-0.2439	-0.2427	1.9420	1.5005	2.5967	-0.2000	-0.2280	-0.1686	1.8646	1.6709	2.1447	0.9347	0.1909	18.136	-0.1787	-0.1892	-0.1727
ϑ_{31}	-101.25	-135.40	-52.137	-189.70	-231.48	-159.55	-251.07	-346.59	-100.39	-5.6747	-6.0959	-5.2336	-245.95	-428.83	-210.76	-182.06	-186.81	-174.14
ϑ_{32}	0.3381	0.1132	0.5422	0.3943	0.1508	0.8904	0.0136	0.0108	0.0185	0.0021	0.0018	0.0023	0.0125	0.0088	1.1734	2.5883	2.4314	2.7074
ϑ_{33}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ϑ_{34}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ϑ_{41}	1314.4	1093.0	1421.6	3173.6	2589.9	4964.5	19047	8486.4	25562	-1957.3	-2526.0	-1420.2	28848	-1217.4	57733	3850.9	3365.1	4034.6
ϑ_{42}	-14.621	-15.930	-10.160	-8.9379	-10.648	-7.8102	0.9417	-0.2475	1.2633	5.6577	4.8614	6.5769	0.9889	-2.2359	2524.1	-206.16	-223.37	-170.70
ϑ_{43}	-13.492	-20.122	-11.303	-20.138	-31.405	-16.842	-122.42	-126.58	-116.80	-111.69	-115.34	-108.02	-222.36	-232.27	-211.44	-18.034	-19.697	-15.817
ϑ_{44}	-10.306	-15.195	-8.6918	-15.207	-23.516	-12.776	-90.634	-93.704	-86.494	-82.720	-85.418	-80.019	-164.34	-171.65	-156.28	-13.655	-14.881	-12.020
c_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
c_2	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0012	0.0012	0.0013	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
d_1	0.0022	0.0011	0.0086	0.0013	0.0006	0.0032	0.1000	0.0259	0.1368	0.3156	0.2586	0.3941	0.3371	0.0004	1.3864	0.0002	0.0002	0.0002
d_2	0.0000	0.0000	0.0000	0.0050	0.0031	0.0146	0.0400	0.0084	0.0606	0.5940	0.5207	0.6359	0.1732	0.0001	3.1820	0.0001	0.0001	0.0001
κ_1	-0.0017	-0.0032	-0.0011	-0.0007	-0.0007	-0.0005	0.0018	-0.0002	0.0023	-0.0059	-0.0070	-0.0048	0.0004	0.0003	0.0007	-0.0002	-0.0002	-0.0001
κ_2	0.0076	0.0066	0.0106	0.0059	0.0059	0.0060	0.0050	0.0044	0.0077	0.0353	0.0340	0.0365	0.0050	0.0042	0.0054	0.0058	0.0057	0.0059
κ_3	-0.0004	-0.0005	-0.0004	-0.0000	-0.0001	-0.0000	-0.0012	-0.0021	-0.0008	-0.0098	-0.0105	-0.0088	-0.0028	-0.0029	-0.0025	-0.0000	-0.0000	-0.0000
κ_4	-0.0057	-0.0079	-0.0050	-0.0039	-0.0041	-0.0039	-0.0049	-0.0058	-0.0025	-0.0415	-0.0432	-0.0401	-0.0003	-0.0008	-0.0000	-0.0018	-0.0019	-0.0017
ρ_1	0.0462	0.0333	0.0920	0.0363	0.0248	0.0565	-0.3134	-0.3663	-0.1584	0.5292	0.4768	0.5964	-0.0048	-0.0158	0.0072	0.0126	0.0124	0.0130
ρ_2	0.0010	-0.0021	0.0020	-0.0601	-0.0819	-0.0519	-0.1981	-0.2426	-0.0912	0.7677	0.7178	0.7934	-0.0162	-0.0491	-0.0009	0.0110	0.0106	0.0115
ρ_3	-0.0707	-0.1594	-0.0450	-0.0324	-0.0736	-0.0176	0.4106	0.2129	0.4730	-2.5328	-2.5713	-2.4222	-0.0429	-0.0984	0.0024	-0.0571	-0.0644	-0.0493
ρ_4	0.0574	0.0419	0.1175	0.0585	0.0484	0.0936	0.4460	0.2122	0.5342	3.4289	3.2793	3.5004	0.0526	0.0016	0.1226	0.0238	0.0195	0.0282
f_0	-3.7956	-4.5335	-3.2963	-2.2359	-3.0284	-1.9274	-3.4242	-3.5175	-3.3188	-58.970	-70.094	-45.868	0.1745	0.0629	1.2127	-22.486	-26.970	-16.313
f_1	-12.360	-86.681	-1.2763	-95414	-146210	-83971	-16593	-25531	-5591.7	-1574.4	-1873.1	-1271.3	-24026	-195013	-9926.9	-20828	-22855	-18398
f_2	464.32	116.84	895.30	788.30	318.62	1732.3	10.579	8.2998	38.658	3.3568	2.7045	4.0399	5.6839	2.3185	2437.6	5838.9	5430.9	6116.5
g_0	-0.3825	-0.4889	-0.1384	-0.3550	-0.3776	-0.3058	-0.5252	-0.8063	-0.1640	0.2902	0.0022	0.4199	-0.3101	-0.3843	-0.2550	-0.0721	-0.0775	-0.0580
g_1	17291	8903.7	23119	25275	20353	28645	41645	16740	57329	854.10	797.23	900.31	40613	34834	59672	29515	28371	30326
g_2	-22.568	-27.151	-10.649	-8.5280	-22.251	-1.8696	-1.4758	-2.3692	-0.0624	-0.1006	-0.1175	-0.0841	-1.6527	-19.372	-1.2855	-5.8063	-9.6764	-3.3393
y_0	0.9864	0.9837	0.9882	0.9920	0.9891	0.9931	0.9877	0.9874	0.9881	0.7885	0.7486	0.8355	1.0006	1.0002	1.0043	0.9194	0.9033	0.9415
y_1	-0.0443	-0.3109	-0.0046	-342.21	-524.39	-301.16	-59.511	-91.569	-20.055	-5.6466	-6.7178	-4.5594	-86.170	-699.42	-35.603	-74.700	-81.971	-65.984
y_2	1.6653	0.4191	3.2110	2.8273	1.1427	6.2130	0.0379	0.0298	0.1386	0.0120	0.0097	0.0145	0.0204	0.0083	8.7425	20.941	19.478	21.937
z_0	0.9993	0.9964	0.9999	0.8549	0.7159	0.9287	0.9750	0.9235	0.9965	0.9667	0.8475	0.9993	-0.6136	-3.1469	-0.2110	0.9923	0.9557	0.9994
z_1	2.3377	0.3002	10.792	10130	5193.6	18051	51.487	-277.34	507.17	-0.4404	-3.9477	0.9400	-3804.2	-6785.8	138186	28.581	-17.357	202.38
z_2	0.0629	-0.0016	0.5353	-2.5072	-3.8263	-0.2911	0.0698	-0.0106	0.5885	0.0019	-0.0000	0.0087	361.32	66.746	351449	2.0201	0.1308	11.3395

Table A.12: Comparison of Model Parameters for Estimations Conditioning on Information in Currency Options: Sample 01/1996 to 10/2008

Using the joint distribution of parameter estimates, we assess whether parameters in A.11 are equal to corresponding estimates in Table A.10. We first calculate empirical p-values for individual parameter tests of equality and subsequently control for the dependency of these tests using conventional Bonferroni corrections and a procedure controlling for false discovery rates; see Benjamini and Hochberg (1995). b, bb, and bbb indicate significance at the 10%, 5%, and 1% levels using the Bonferroni corrections. f, ff, and fff indicate significance at the 10%, 5%, and 1% levels when controlling for false discovery rates.

	AUD	CAD	CHF	DEM-EUR	GBP	JPY
φ_1	–	–	–	–	–	–
φ_2	–	–	–	–	–	bbb/fff
φ_3	–	bbb/fff	–	–	–	–
φ_4	–	–	–	bbb/fff	f	bbb/fff
ϑ_{11}	–	–	–	–	–	–
ϑ_{12}	–	–	–	–	–	bbb/fff
ϑ_{21}	–	–	–	bbb/fff	–	–
ϑ_{22}	–	–	–	–	–	–
ϑ_{31}	–	–	–	–	–	–
ϑ_{32}	–	–	–	–	–	–
ϑ_{33}	–	–	–	–	–	–
ϑ_{34}	–	–	–	–	–	–
ϑ_{41}	–	bbb/fff	–	bbb/fff	–	bbb/fff
ϑ_{42}	–	bbb/fff	–	bbb/fff	–	–
ϑ_{43}	–	–	–	–	–	bbb/fff
ϑ_{44}	–	–	–	–	–	bbb/fff
c_1	–	–	–	–	–	–
c_2	–	–	–	–	–	–
d_1	–	–	–	–	–	–
d_2	–	–	–	–	–	–
κ_1	–	–	–	–	–	–
κ_2	–	–	–	–	–	–
κ_3	–	–	–	–	–	–
κ_4	–	–	–	–	–	–
ρ_1	–	–	–	ff	–	–
ρ_2	–	–	–	–	–	–
ρ_3	–	–	–	–	–	bbb/fff
ρ_4	–	–	–	–	–	–
f_0	–	bbb/fff	–	–	–	–
f_1	–	–	–	–	–	–
f_2	–	–	–	–	–	–
g_0	–	–	–	–	–	–
g_1	–	–	–	–	–	–
g_2	–	–	–	–	–	–
y_0	–	bbb/fff	–	–	–	–
y_1	–	–	–	–	–	–
y_2	–	–	–	–	–	–
z_0	–	–	–	–	–	–
z_1	–	–	–	–	bbb/fff	–
z_2	–	–	–	–	–	–

Table A.13: Yield Pricing Errors and Matching Depreciation Rates: Sample until December 2006

The table reports pricing errors for domestic (US) and foreign yields as well as results for how well model implied depreciation rates match observed rates. Columns labeled "Yield Pricing Errors" report annualized root mean squared errors in basis points for the yield maturities indicated in the header. Columns labeled "Matching Depreciation Rates" report correlations of model implied and observed rates ("corr") and results of regressing the later on the former with c_0 denoting the intercept, c_1 the slope coefficient, and se($\cdot$) the respective block-bootstrapped standard errors in parentheses. R^2 is the in-sample coefficient of determination. The results are for the global model described in section *3.1* based on daily observations for the sample periods are October 12, 1994 to December 29, 2006 for AUD; June 1, 1993 to December 29, 2006 for CAD; and September 18, 1989 to December 29, 2006 for CHF, DEM-EUR, GBP, and JPY.

	Yield Pricing Errors							Matching Depreciation Rates					
	1m	3m	6m	1y	2y	3y	4y	corr	c_0	se(c_0)	c_1	se(c_1)	R^2
USD	5	4	6	17	15	11	23						
AUD	6	7	9	14	18	24	41	0.9990	-0.0000	(0.0000)	1.0171	(0.0010)	0.9981
CAD	9	10	11	17	30	44	68	0.9845	-0.0000	(0.0000)	0.9908	(0.0043)	0.9693
CHF	8	9	9	16	29	41	55	0.9365	0.0000	(0.0000)	0.9940	(0.0072)	0.8771
DEM-EUR	12	15	14	17	39	61	84	0.9990	0.0000	(0.0000)	1.0239	(0.0008)	0.9980
GBP	10	11	10	24	38	58	89	0.9554	0.0000	(0.0000)	1.1636	(0.0097)	0.9129
JPY	7	10	12	19	28	50	82	0.8804	0.0001	(0.0000)	1.0241	(0.0178)	0.7752

Table A.14: Regressions of Excess Returns on Expected Excess Returns: Sample until December 2006

The table shows the results from estimating, by ordinary least squares, the regression (23), $ER_{t,T} = \alpha' + \beta' \widehat{ER}_{t,T} + \eta'_{t,T}$, for the horizons indicated in the column headers. Values in parentheses are block-bootstrapped standard errors. $t[\beta' = 1]$ is the t-statistic for testing $\beta' = 1$. R^2 is the in-sample coefficient of determination. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to December 29, 2006 for AUD; June 1, 1993 to December 29, 2006 for CAD; and September 18, 1989 to December 29, 2006 for CHF, DEM-EUR, GBP, and JPY.

	1 day	1 week	1 month	3 months	1 year	4 years
AUD						
α'	−0.0000	−0.0002	−0.0010	−0.0019	0.0039	0.0083
se(α')	(0.0001)	(0.0006)	(0.0026)	(0.0061)	(0.0185)	(0.0857)
β'	0.3285	0.3402	0.3488	0.7917***	1.2774***	0.5761
se(β')	(0.2890)	(0.2825)	(0.2755)	(0.2227)	(0.1460)	(0.4098)
$t[\beta' = 1]$	[-2.32]	[-2.34]	[-2.36]	[-0.94]	[1.90]	[-1.03]
R^2	0.0011	0.0062	0.0238	0.2369	0.7198	0.2917
CAD						
α'	−0.0001	−0.0003	−0.0012	−0.0027	−0.0003	0.0062
se(α')	(0.0001)	(0.0003)	(0.0012)	(0.0034)	(0.0096)	(0.0340)
β'	0.4318*	0.5349**	0.5382**	0.6282***	1.0288***	0.8464**
se(β')	(0.2500)	(0.2426)	(0.2560)	(0.2358)	(0.2765)	(0.3686)
$t[\beta' = 1]$	[-2.27]	[-1.92]	[-1.80]	[-1.58]	[0.10]	[-0.42]
R^2	0.0009	0.0060	0.0271	0.1043	0.5194	0.4570
CHF						
α'	0.0000	0.0001	0.0002	0.0010	0.0014	0.0036
se(α')	(0.0001)	(0.0006)	(0.0027)	(0.0073)	(0.0235)	(0.0425)
β'	0.3798***	0.6031***	0.7641**	1.0403***	1.0369**	0.9146***
se(β')	(0.0914)	(0.1359)	(0.3426)	(0.3772)	(0.4078)	(0.2908)
$t[\beta' = 1]$	[-6.78]	[-2.92]	[-0.69]	[0.11]	[0.09]	[-0.29]
R^2	0.0038	0.0170	0.0267	0.0868	0.2413	0.3319
DEM-EUR						
α'	0.0000	0.0001	0.0006	0.0009	0.0025	0.0022
se(α')	(0.0001)	(0.0005)	(0.0024)	(0.0063)	(0.0213)	(0.0519)
β'	1.2621***	0.9379***	0.8902**	0.9634**	1.0362**	0.7076**
se(β')	(0.3122)	(0.3341)	(0.3656)	(0.3858)	(0.4316)	(0.3035)
$t[\beta' = 1]$	[0.84]	[-0.19]	[-0.30]	[-0.09]	[0.08]	[-0.96]
R^2	0.0033	0.0085	0.0319	0.0897	0.2765	0.2465
GBP						
α'	0.0002**	0.0006	0.0025	0.0061	0.0198	0.0209
se(α')	(0.0001)	(0.0005)	(0.0025)	(0.0077)	(0.0198)	(0.0398)
β'	−1.7946	−0.8173	−0.3884	−0.0375	−0.0365	0.7485*
se(β')	(1.3293)	(1.3965)	(1.4380)	(1.4750)	(0.9902)	(0.4138)
$t[\beta' = 1]$	[-2.10]	[-1.30]	[-0.97]	[-0.70]	[-1.05]	[-0.61]
R^2	0.0016	0.0011	0.0010	0.0000	0.0001	0.2515
JPY						
α'	0.0001	−0.0003	−0.0011	−0.0037	−0.0065	−0.0117
se(α')	(0.0003)	(0.0009)	(0.0027)	(0.0071)	(0.0227)	(0.0465)
β'	0.9237***	0.8238***	0.4083*	0.7152**	1.0602***	0.9134***
se(β')	(0.0877)	(0.1519)	(0.2271)	(0.2893)	(0.2707)	(0.1968)
$t[\beta' = 1]$	[-0.87]	[-1.16]	[-2.61]	[-0.98]	[0.22]	[-0.44]
R^2	0.1974	0.1913	0.0168	0.0493	0.3368	0.6157

Table A.15: Ability to Predict Excess Returns: Sample until December 2006

The table reports results related to the predictive ability of the model as compared to the UIP and RW benchmarks. Hit-ratios (HR) are calculated as the proportion of times the sign of the excess return is correctly predicted by the model. $R2 = 1 - MSE_M/MSE_B$ where MSE_M denotes the mean squared prediction error of the model and MSE_B that of the benchmark. CW and GW denote the test-statistics of Clark and West (2007) and Giacomini and White (2006) as described in Section *3.3*. The one-sided p-values of the test-statistics in square brackets are obtained from the block bootstrap procedure described in Appendix F which accounts for autocorrelation and heteroscedasticity. The results are based on non-overlapping observations for horizons up to 1 month and on monthly frequency for horizons of 3 months and beyond. The sample periods are October 12, 1994 to December 29, 2006 for AUD; June 1, 1993 to December 29, 2006 for CAD; and September 18, 1989 to December 29, 2006 for CHF, DEM-EUR, GBP, and JPY.

	Model vs. UIP						Model vs. RW					
	1d	1w	1m	3m	1y	4y	1d	1w	1m	3m	1y	4y
AUD												
HR	0.5238	0.5507	0.6162	0.7475	0.8485	0.5960	0.5238	0.5507	0.6162	0.7475	0.8485	0.5960
$R2$	0.0013	0.0069	0.0270	0.2459	0.7207	0.2974	0.0006	0.0030	0.0092	0.1990	0.6763	0.2917
p-value[CW]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.026]	[0.014]	[<0.01]	[0.019]	[<0.01]	[<0.01]	[0.014]
p-value[GW]	[0.218]	[0.186]	[0.154]	[<0.01]	[<0.01]	[<0.01]	[0.249]	[0.216]	[0.192]	[0.010]	[<0.01]	[<0.01]
CAD												
HR	0.5386	0.5406	0.5478	0.5652	0.7217	0.5652	0.5386	0.5406	0.5478	0.5652	0.7217	0.5652
$R2$	0.0014	0.0085	0.0411	0.1299	0.5220	0.4878	0.0004	0.0036	0.0240	0.0704	0.4153	0.4690
p-value[CW]	[0.026]	[0.024]	[0.021]	[<0.01]	[<0.01]	[0.014]	[0.160]	[0.133]	[0.080]	[0.015]	[<0.01]	[0.026]
p-value[GW]	[0.028]	[0.192]	[0.123]	[0.021]	[0.034]	[<0.01]	[0.048]	[0.218]	[0.224]	[0.040]	[0.075]	[<0.01]
CHF												
HR	0.5279	0.5387	0.5786	0.6352	0.7736	0.7421	0.5279	0.5387	0.5786	0.6352	0.7736	0.7421
$R2$	0.0038	0.0171	0.0269	0.0868	0.2423	0.3527	0.0030	0.0134	0.0106	0.0484	0.1366	0.2113
p-value[CW]	[<0.01]	[<0.01]	[0.029]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.157]	[0.042]	[<0.01]	[<0.01]
p-value[GW]	[0.068]	[0.135]	[0.168]	[0.045]	[0.025]	[<0.01]	[0.128]	[0.261]	[0.303]	[0.084]	[0.074]	[<0.01]
DEM-EUR												
HR	0.5371	0.5516	0.5535	0.6289	0.7799	0.7547	0.5371	0.5516	0.5535	0.6289	0.7799	0.7547
$R2$	0.0033	0.0086	0.0324	0.0901	0.2765	0.2477	0.0027	0.0058	0.0189	0.0526	0.1581	0.1367
p-value[CW]	[<0.01]	[<0.01]	[0.012]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.022]	[0.033]	[0.013]	[<0.01]	[<0.01]
p-value[GW]	[0.149]	[0.070]	[0.098]	[0.019]	[0.017]	[<0.01]	[0.093]	[0.044]	[0.121]	[0.024]	[0.048]	[<0.01]
GBP												
HR	0.5085	0.5201	0.5283	0.5535	0.5283	0.6289	0.5085	0.5201	0.5283	0.5535	0.5283	0.6289
$R2$	0.0020	0.0026	0.0073	0.0145	0.0476	0.4256	0.0016	0.0006	-0.0018	-0.0068	-0.0104	0.4598
p-value[CW]	[0.946]	[0.573]	[0.403]	[0.175]	[0.172]	[<0.01]	[0.746]	[0.340]	[0.319]	[0.205]	[0.037]	[<0.01]
p-value[GW]	[0.050]	[0.504]	[0.382]	[0.248]	[0.201]	[<0.01]	[0.070]	[0.451]	[0.425]	[0.283]	[0.147]	[<0.01]
JPY												
HR	0.6371	0.6418	0.5409	0.6541	0.7736	0.9371	0.6371	0.6418	0.5409	0.6541	0.7736	0.9371
$R2$	0.1974	0.1915	0.0181	0.0529	0.3430	0.6690	0.1966	0.1881	-0.0020	0.0026	0.1879	0.4923
p-value[CW]	[<0.01]	[<0.01]	[0.080]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[<0.01]	[0.208]	[0.071]	[<0.01]	[0.011]
p-value[GW]	[<0.01]	[<0.01]	[0.250]	[0.111]	[0.012]	[<0.01]	[<0.01]	[<0.01]	[0.487]	[0.206]	[0.019]	[<0.01]